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Identification of Subsoil Compaction Using Electrical Conductivity and Spectral Data Across Varying Soil Moisture Regimes in Utah

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IDENTIFICATION OF SUBSOIL COMPACTION USING ELECTRICAL

CONDUCTIVITY AND SPECTRAL DATA ACROSS VARYING

SOIL MOISTURE REGIMES IN UTAH

by

Jay M. Payne

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Approved:

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ABSTRACT

Identification of Subsoil Compaction Using Electrical Conductivity and Spectral Data Across Varying Soil Moisture Regimes in the Intermountain West

by

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Utah State University, 2008

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Subsoil compaction is a major yield limiting factor for most agricultural crops. Tillage is the most efficient method to quickly treat compacted subsoil, but it is also expensive, increases erosion, and accelerates nutrient cycling.

The use of real-time electrical conductivity (EC) and near-infrared (NIR) reflectance values to differentiate compacted areas from uncompacted areas was studied. This method has potential to reduce monetary and time investments inherent in traditional grid sampling and the resultant deep tillage of an entire field. EC and NIR reflectance are both very sensitive to spatial variability of soil attributes.

The objective of this research was to determine whether the amount of soil moisture affects the efficacy of EC and NIR spectroscopy (at 2151.9 nm) in identifying subsoil compaction through correlation analysis, and also to determine whether a minimum level of compaction was necessary for these same methods to detect compaction in three different soil textures across a variable water gradient.

Bulk density measurements were taken in late 2007 from plots traversing an induced soil moisture gradient, and low, medium, and high levels of compaction at three locations with different soil textures. A Veris Technologies (Salina, KS) Near-Infrared Spectrophotometer equipped with an Electrical Conductivity Surveyor 3150 was used to measure and geo-reference EC and NIR reflectance data over the same plots. Analysis of the data for a correlation between compaction (bulk density values) and EC, as well as compaction and NIR reflectance, produced clear results.

It was found that electrical conductivity is not significantly different between compacted or uncompacted soils even when tested at all moisture extremes and in different soil textures in Utah. Also, NIR spectroscopy was unsuccessful at identifying subsoil compaction because all tested procedures to induce a spectrometer into the soil resulted in changes the physical properties of the soil.

(89 pages)

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Jay M. Payne

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The average farm size in the United States has nearly doubled within the last 50 years. At the same time, farmed acreage has decreased. This demands higher yields from less acres to maintain production levels (USDA, 2007). Farmers now need larger equipment in order to optimize efficiency and treat more acreage in a shorter amount of time. As shown below, U.S. producers in general have adapted to increase production, the management practices used have, in some cases, created new challenges. Subsoil compaction is one result of the use of larger tractors and implements and the practice of intense tillage.

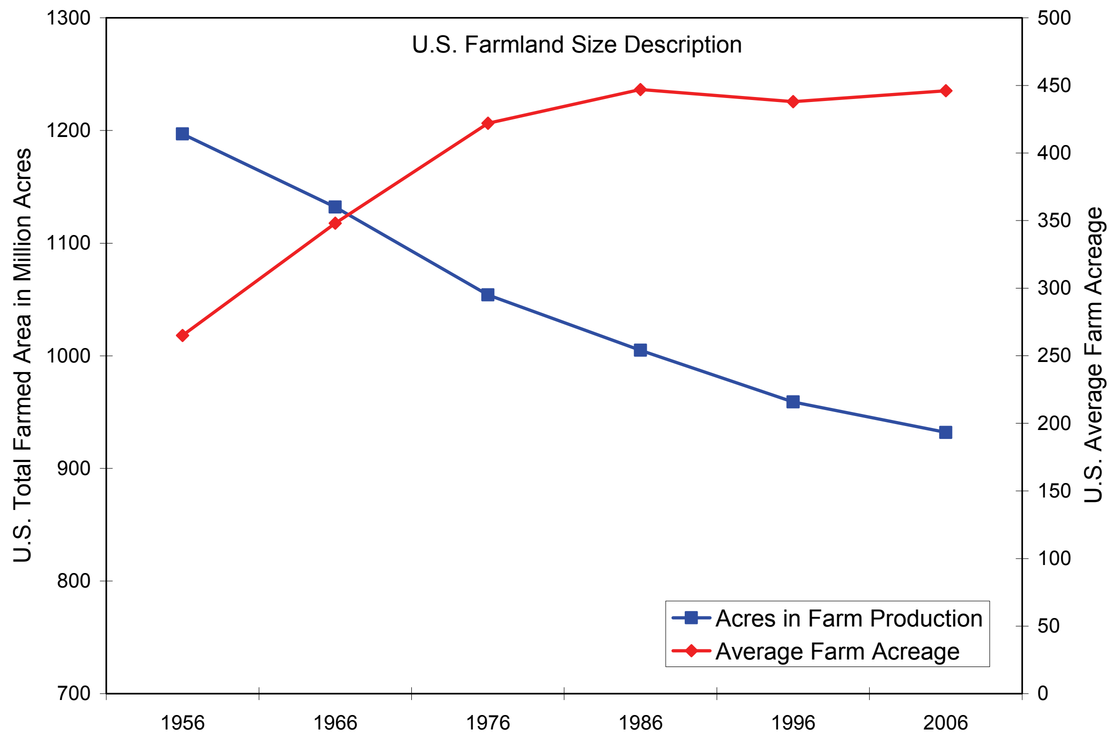


Figure 1. Total United States farmed area and average farm size for 1956-2006 (USDA, 2007).

Subsoil compaction has negative effects on crop establishment, growth, and yield. Yield reductions of up to 38% have been documented in wheat (*Triticum aestivum L.*) and up to 50% in maize (*Zea mays L.*) (Sidhu and Duiker, 2006). While the negative impacts of soil compaction are significant, these effects are normally short-lived because subsequent tillage can alleviate compacted conditions.

However, tillage also has detrimental effects on soils. While it can alleviate compaction in some cultivated areas, tillage also causes compaction in other parts of the soil profile. Tillage increases soil erosion potential, accelerates loss of soil organic matter (SOM) in the surface layers, and causes a flush of soil nutrients by accelerating natural nutrient cycling. This results in increased fertilization needs, and increases labor and equipment costs. To remedy this conflict between benefits and drawbacks of tillage, some producers use conservation tillage methods. Conservation tillage is any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water (CTIC, 1996). Where soil erosion by wind is the primary concern, any system that maintains the equivalent of at least 1000 pounds per acre of flat, small grain residue on the surface during the critical wind erosion period is considered conservation tillage. The type of tillage operations prior to and at planting affects the amount of residue on the surface (CTIC, 1996).

Precision agriculture, or site-specific agriculture, is the science of using technology to solve agricultural problems through a better understanding of spatial and temporal variability of agronomic attributes. Once understood, site-specific agriculture is used to “treat the soil, not the field.” It has the potential to alter decision making in agricultural production and to simultaneously achieve the objectives of enhancing conservation tillage inputs and efficiency, reducing environmental pollution, increasing farm profits, and safeguarding a sustainable agriculture industry. There is a great need to develop site-specific tillage sensors and practices that can rapidly identify subsoil compaction (Srinivasan, 2006). Information about the location of compacted areas would allow a producer to employ the beneficial effects of tillage to compacted areas without the detrimental effects and costs of treating entire fields. Site-specific tillage involves delivering prescribed treatments to affected areas only. This reduces labor, maintenance, and fuel costs while optimizing an established conservation tillage system. The amount of energy conserved, and therefore money saved, by deep tilling only where it is needed, is very significant to a producer (Mouazen and Ramon, 2005).

Current applications of real-time sensor data does not include a method to rapidly identify subsoil compaction. Electrical conductivity through the bulk soil is known to correlate well with changing soil characteristics including soil salinity, clay content, cation exchange capacity (CEC), clay mineralogy, soil pore size and distribution, and soil moisture content and temperature (McNeill, 1992; Rhoades et al., 1999; Sudduth et al., 2003). Rhoades et al.,(1989) developed a controversial model claiming electrical conductivity uses compacted soil particles as one of three electrical pathways through the bulk soil mass. Several researchers have attempted to define the influence of this electrical pathway but have not been able to isolate it from less resistant routes for EC through the soil.

Near-infrared reflectance spectroscopy (NIRS) is another measurement that is highly sensitive to changing soil physical and chemical attributes. It is well documented that NIRS can be used to classify moisture content, total C, total N, particle-size distribution, CEC, pH, extractable Ca, K, Mg, and potentially mineralizable N (Chang et al., 2001; Shepherd and Walsh, 2002; Nanni and Demattê, 2006).

This project attempted to create conditions where the electrical pathway on the compacted soil particles would be the least resistant of the three routes through bulk soil. If strong correlations exist between EC and subsoil compaction, in-situ EC sensors could be used to rapidly identify subsoil compaction zones. These would be used in site-specific tillage management systems. In addition, near-infrared reflectance (NIR) values were compared with soil bulk density to establish whether the measurements of a near-infrared spectrometer will correlate to compacted soil conditions over variable water content, compaction levels, and textures at three sites in the Intermountain West.

It was hypothesized that measured bulk electrical conductivity would increase as compaction, represented by soil bulk density, increased. Further, we felt this relationship would only exist where induced compaction by wheel traffic and uniform tillage had occurred in the driest extremes of the soil moisture gradients that would be created. Finally, we felt that this effect would be more evident in sandier soils at Greenville and Kaysville. This is because sand has less inherent capacity to conduct electrical current.

It was also hypothesized that near-infrared reflectance would directly correlate with compaction in the induced compaction treatments in dry soils. This was hypothesized to be due to the effects of geometry of the soil on NIR reflectance when the soil was compacted. Finally, we investigated whether influences of soil moisture would confound reflectance values when compared to a uniformly dry soil.

A statistical analysis of variance (ANOVA) was carried out for each combination sampled. The null hypothesis of this test states that the sample population means for the bulk density measurements will be similar to the population means for EC or reflectance values of the same plot. Acceptance of the null hypothesis signifies that there is no difference between the measured values, or, that EC and NIR reflectance cannot be used with any confidence to identify subsoil compaction. Rejection of the null hypothesis implies that the population means are not equal, or, that subsoil compaction can be identified through a regression equation that predicts bulk density with an acceptable degree of confidence.

Null and Alternative Hypotheses

$$H_O: \mu_{BD\ Shallow} = \mu_{EC\ Shallow} = \mu_{EC\ Deep} = \mu_{NIR}$$
$$: \mu_{BD\ Deep} = \mu_{EC\ Shallow} = \mu_{EC\ Deep} = \mu_{NIR}$$

$$H_A: \mu_i \neq \mu_j \text{ for some } i \text{ and } j$$

OBJECTIVES

The primary objective was to determine whether site-specific agricultural sensors measuring bulk soil electrical conductivity and near-infrared reflectance could be used to effectively identify subsoil compaction in the Intermountain West. Included in this main objective were four questions:

1. Does the amount of soil moisture influence the level at which the conductive pathway will follow compacted soil particles?
2. Is there a minimum level of compaction required to be able to detect subsoil compaction utilizing apparent soil electrical conductivity values?
3. Does a relationship exist between soil compaction and soil texture (found at different experimental plots) that could help to identify areas with subsoil compaction?
4. Do NIR reflectance values (2151.9 nm) correlate to known areas of compacted subsoil?

LITERATURE REVIEW

SOIL PROPERTIES

Soil Compaction

Compacted soil is a yield-limiting physical characteristic commonly found in cultivated agricultural fields. Soil compaction is the process by which the soil particles are rearranged to decrease void space, thereby increasing bulk density (SSSA, 1997). Bulk density is the most commonly used figure to describe compacted soil. Hillel (2004) defines bulk density (ρ_b) as the ratio of the mass of solids (M_s) to the total soil volume (V_t). It is normally expressed in terms of g cm^{-3}.

$$\rho_b = M_s / V_t = M_s / (V_{soil} + V_{air} + V_{water})$$

Soil bulk density values are most useful when comparing compaction levels at two or more locations or depths. Because plants tolerate and thrive on different levels of soil bulk density, the severity of compacted conditions is impossible to define within typical values. Optimal conditions are subject to the ideal range of soil bulk density best suited for the crop in question. Bulk density is also an elusive characteristic to measure, considering the extreme variability that exists in every soil profile and in any sampling scheme. Changes in texture, structure, moisture, soil strength, the presence of rock, etc., all affect the quality of the sample.

Soil compaction affects physical, chemical, and biological properties of the soil as well as impeding root growth and increasing a given soil's erosion potential. The zone of compaction is much greater than just where the tire or blade touches the soil (Soehne, 1958). The product of the vertical component of surface stress with the surface area on which it acts is equal to the total weight carried on any wheel or track. Theory suggests that the total axle load is a much more significant factor in controlling deep soil compaction than the surface contact pressure (Abu-Hamdeh et al., 2000). Soehne (1958) studied the effects of different load distributions and the resulting pressures on the soil at increasing depths and concluded that, "the pressure in the upper soil layer is determined by the specific pressure at the surface, and the pressure in the deeper soil layer is determined by the amount of load."

All cropping systems are negatively impacted when bulk densities approach the point where roots can no longer penetrate. Preliminary studies for this project were conducted by the author. Twelve PVC tubes were filled with the same sandy loam soil and compacted to create two replications of high, medium, and low bulk density treatments. Two corn seeds were planted into each of six tubes, with two tubes from each compaction treatment. In the same manner, soybeans were also planted into the remaining six tubes. After exposure to equal amounts of light, temperature, and nutrient solution in a controlled environment, the results of compaction on plant growth were visibly evident in the following photograph. Root and shoot limitations of corn and soybeans occurred, even between bulk density differences as small as 1.22 g cm^{-3} and 1.33 g cm^{-3}. It was clearly evident that soil compaction limits crop yields.

Poincelot (1986) found that corn yields were reduced by up to 50% on compacted clay soils compared with similar uncompacted soils. Abu-Hamdeh (2003) studied compaction and subsequent subsoiling effect on corn growth and bulk density.

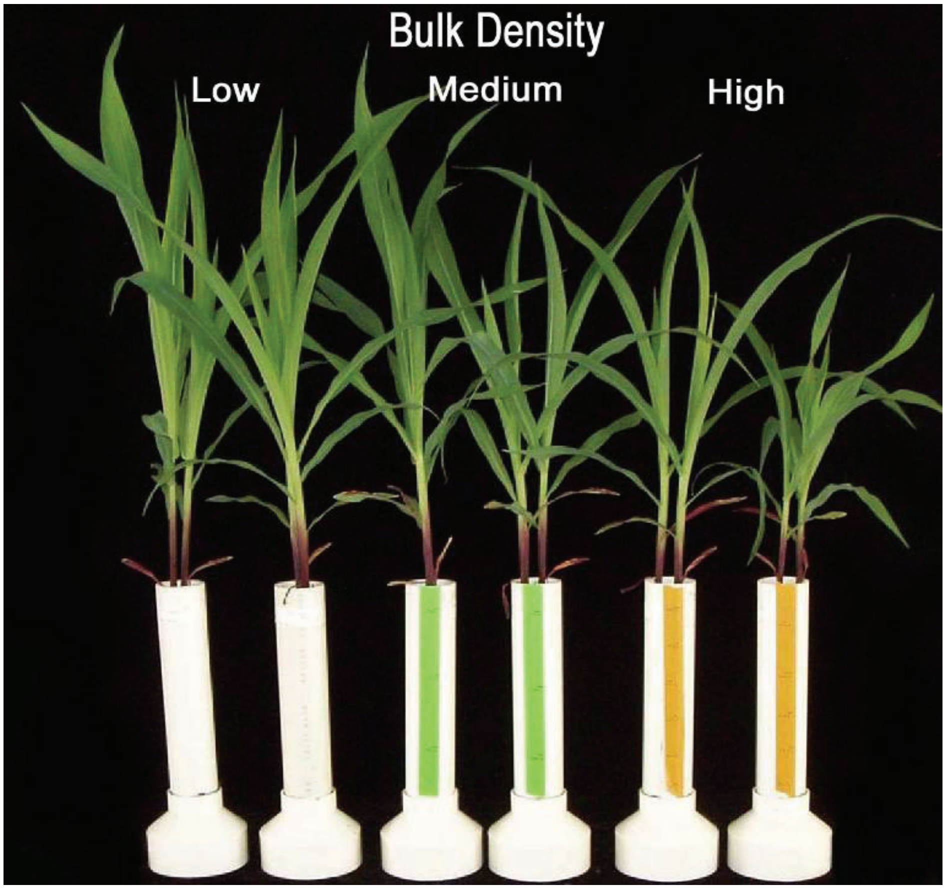


Figure 2. Evidence of effects of high bulk density on crop yield

Measuring compaction by calculating bulk density from core samples taken from each plot, he found that plots that were never compacted had greater yields than those that were compacted and later subsoiled, but subsoiled plots were better than the plots that were left compacted.

Soil Electrical Conductivity

Research has shown that spatially referenced apparent electrical conductivity (EC) data is a useful tool to characterize the variable nature of soils (Lund et al., 1999; Corwin and Lesch, 2003; Corwin and Plant, 2005; Jung et al., 2005). Electrical conductivity is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of milliSiemens per meter (mS m^{-1}). Soil EC measurements are also commonly reported as deciSiemens m^{-1} (Deorge et al., 2007). Integrating a global positioning system (GPS) and EC sensors allows researchers to analyze and display soil attributes on a map easily.

A soil profile is a three-phase composition of solids, liquids, and air. Water, dissolved minerals, roots, air, etc. move through the soil constantly. When electrical current is introduced into the soil, it also flows through this medium, however, it is not clearly understood as to whether it travels though all three parts of the soil profile. These three pathways through which electricity may flow are defined by Corwin and Lesch (2005) as:

1. A liquid phase conductive pathway via dissolved solids contained in the soil's water occupying the large pores.
2. A solid-liquid phase conductive pathway primarily via exchangeable cations associated with clay minerals.
3. A solid-solid conductive pathway via soil particles that are in direct and continuous contact with one another.

Rhoades et al., (1999) and Corwin and Lesch (2005) claim that all three electro-chemical pathways contribute to the apparent soil electrical conductivity. However, Friedman (2005) reports that the solid-solid phase of heterogeneous soils is non-conducting. Such conflicting definitions complicate the theory, but are not critical to whether or not anthropogenic soil attributes, such as compaction, are able to be detected with the use of EC sensors. The interactions between physical, chemical, electro-chemical, anthropogenic, meteorological, and geologic characteristics are so interrelated that a variation of one property inevitably affects another property's effect on conductivity pathways.

When yield maps were found to correlate strongly with bulk soil EC maps from the same fields, producers and researchers sought to establish which soil properties affect bulk soil EC values. Several researchers (Lund et al., 1999; Gorucu et al., 2001; Corwin and Lesch, 2003; Corwin and Plant, 2005; Jung et al., 2005; Deorge et al., 2007) have outlined many of the correlations between bulk soil electrical conductivity and other soil characteristics. Correlations with apparent electrical conductivity exist for both directly measured soil properties and indirectly measured soil properties. Corwin and Lesch (2005) organized literature citations for the following categories of soil attributes that correlate with apparent soil EC: salinity and nutrients, water content attributes, textural attributes, bulk density (compaction), organic matter, cation exchange capacity, leaching, ground water recharge, herbicide partition coefficients, soil map unit boundaries, corn rootworm distribution, and soil drainage classes. All of the mentioned attributes influence the conductivity of the bulk soil, however it is difficult to distinguish which conductive pathway(s) is being followed. Electricity will primarily follow the pathway of least resistance.

Soil pore continuity affects bulk EC as water-filled pore spaces transmit electricity very well. The soil texture and structure cause the continuity to change. Clay soils tend to aggregate better and typically have more pore space than coarse textured soils. Deorge et al.,(2007) mention, while talking about the relationship between EC and pore continuity, that “curiously, compaction will normally increase soil EC.” Soil compaction induced through tillage practices or wheel traffic affects the geometry and topology of the aqueous phase by changing the configuration of the solid-phase attributes (Friedman, 2005). Thus, changing the re-arrangement of particles caused by compaction may affect the EC of the bulk soil.

The Rhoades et al., (1999) model also indicates that compaction would increase EC values in the third phase, through solids. By aligning soil particles into a compacted state, a continuous particle-to-particle connection would transmit electricity through the soil profile to a higher degree than un-compacted soils.

Because of the broad spectrum of soil characteristics that change the electrical conductivity of soils, it is difficult to isolate the effect of any one of these attributes. Researchers have alluded to the possibility of identifying subsoil compaction with EC sensors but have not explained the influence of the other conductivity-influencing factors. Gorucu et al.,(2001) found strong negative correlations between soil EC and predicted tillage depths through the use of draft force strain gauges. These results however, were a product of textural changes and not of cultivation-induced compaction. Jung et al.,(2005) found that bulk density was generally not well correlated with EC in 0-15 cm depths. However, at depths from 15-30 cm EC was negatively correlated with bulk density. This correlation was attributed to the claypan horizon at these depths. These deep bulk density correlations closely followed the values for correlation between EC and cation exchange capacity (CEC) from increased clay content. Once again, because pore space increases with clay content, bulk density also decreases resulting in the strong negative correlation.

Heiniger et al.,(2003) suggest that the most important factor influencing EC is the volumetric water content of the soil (liquid phase) when the soil is near saturation. When the volumetric water content of the soil is low, the primary conductive pathway was through the soil-particle and discontinuous soil pore pathway. They found that the soil structure does not provide enough direct particle-to-particle contact to form a continuous pathway through solids when sufficient moisture is not present. Heiniger et al.,(2003) showed that even nutrient concentrations were associated with texture and its effect on volumetric particle content, volumetric water content, or both. This shows an indirect and incomplete link between conclusions about the ability to identify compaction without considering other variables.

Johnson et al.,(2001) looked for correlations between apparent soil electrical conductivity and physical and chemical attributes on a farm in the semiarid Central Great Plains. This study is significantly different from others because of the average precipitation level being only 420 mm (16.5 in) annually, which is similar to precipitation patterns in Utah. Likely, this would result in less of a hardened claypan at a certain depth. Similar to other researchers, Johnson et al.,(2001) found that clay content had a positive correlation ($r = .50$ significant at the 0.001 probability level) to bulk EC values. However, they also found a positive correlation ($r = .49$ significant at the 0.001 probability level) between apparent electrical conductivity and bulk density (compaction). Water content during these measurements was between 12-16%. The level of compaction is unknown and was not reported. Although this is not a strong correlation, it indicates that it may be possible to develop a model for arid climates, without dominate argilic horizons, for using electrical conductivity to identify subsoil compaction, without submitting to expensive and time consuming grid sampling. In the low precipitation areas common to the West, heavy claypans are not as common as in the rain-fed agriculture in the South and Midwest regions. Also, it is not clear how a sandy soil with a compacted plowpan will affect electrical conductivity through the soil.

No other literature has been found about experimentation to find a correlation between EC and subsoil compaction, isolated from other factors, in soils without claypans in semiarid areas. The question still remains whether there is a correlation between EC and bulk density in the Intermountain West. Literature that has shown a relationship is mainly due to either moisture trends or claypans in other regions of the country.

Near-Infrared Reflectance Spectroscopy (NIRS)

NIRS normally involves a light source emitting near-infrared (NIR) radiation into the soil. The size, shape, arrangement, and chemistry of soil particles influence the degree that certain wavelengths of light will be reflected, transmitted, and absorbed by the bulk soil. Because soils are opaque, very little shortwave radiation is transmitted (Chang et al., 2001; Stephens, 2006). This property makes soil reflectance values extremely sensitive to many different soil attributes. The absorbance values, which are derived from the measured reflectance from a known light source at each wavelength, indicate a difference in the inherent properties of that soil. Through conventional soil analysis, a relationship between these properties and the obtained absorbance data is established and represented in tables and geographically in the form of field maps. Because these factors also affect important soil fertility, hydraulic, and thermal properties, it is beneficial to geographically identify areas of interest for site-specific management of agricultural or environmental resources.

NIRS has come to the forefront of precision agriculture research in the last two decades as it has been used to efficiently classify the soil attributes of large areas. Previously, detailed soil maps were painstakingly assembled through a process of destructive grid sampling, laboratory analysis, and statistical interpretation. NIRS allows researchers to cover more area in very little time, and with better detail. This timely data facilitates the relevancy of in-field comparisons with ephemeral data such as soil moisture, volatile nutrients, etc. (Chang et al., 2001).

Many soil characteristics have been found to correlate well with portions of the shortwave spectrum. These significant and highly correlated properties include moisture content, total C, total N, particle-size distribution, CEC, pH, extractable Ca, K, Mg, and potentially mineralizable N (Chang et al., 2001; Shepherd and Walsh, 2002; Nanni and Demattê, 2006). In addition, Nanni and Demattê (2006) found correlations with the sum of cations, Fe_2O_3 and TiO_2. The above studies have been carried out to develop models, or libraries of information for models, with which to predict soil characteristics through the use of NIRS. However, none of these findings were done with in-situ measurements; all were extracted field samples, which were then dried, ground, and analyzed with a spectrophotometer in a laboratory. Coleman et al., (1991) found that correlations for particle-size distribution, OM, and Fe_2O_3 from in-field measurements were significantly weaker than when measured using laboratory equipment..

No available literature has been found in regard to the use of NIRS to identify subsoil compaction. Stephens (2006) used the ASTER 6 band (2185-2225 nm) as one variable in models for both soil water content and soil organic carbon for the same plots used in this experiment on the Greenville Experiment Farm in Logan, UT. This shows that significant differences are present in two attributes related to soil compaction, moisture content and soil C content. It is assumed that, if any reflectance values correlate to subsoil compaction, a wavelength in this band would very likely indicate that difference.

SENSORS

Due to its ease of measurement, reliability, and relative low cost, soil apparent electrical conductivity has become one of the most reliable and frequently used measurements to characterize spatial variability within a field for application to precision agriculture (Rhoades et al., 1999; Corwin and Lesch, 2003, 2005; Srinivasan, 2006). Several sensors are commercially available to collect EC data.

Near-infrared reflectance spectroscopy is also a widely used measurement of variability in plants and soils. Precision agriculture may employ NIRS for purposes such as irrigation scheduling, early detection of chlorosis and nutrient deficiency, vegetation indices, and site-specific pesticide and nutrient application. NIRS measurements are made from many platforms such as satellites, aircraft, in-field, and laboratory-based instruments.

Veris Technologies (Salina, KS) recently (2006) introduced a Near Infrared Spectrophotometer with the EC Surveyor 3150 module (known as the VERIS NIRS) on a ground-engaging, real-time platform that is drawn through a field by truck or tractor. The EC Surveyor 3150 module collects conductivity data in both shallow (0-25 cm) and deep

Figure 3. The Veris Technologies NIRS traversing the plots at the Greenville Research Farm in North Logan, Utah.

(0-75 cm) modes in mS/m. The NIR spectrophotometer, seen above, also simultaneously gathers reflectance values at an adjustable depth from 4-10 cm. The response range is from 400-2200 nm with a spectral resolution of 8 nm. All measurements are georeferenced with a Garmin global positioning system that is differentially corrected through the wide-area augmentation system.

Electrical conductivity sensors introduce an electrical current into the soil through current electrodes; in this case, flat, metal coulters inserted perpendicular to the soil's surface. Current is introduced through one electrode and the difference in current flow

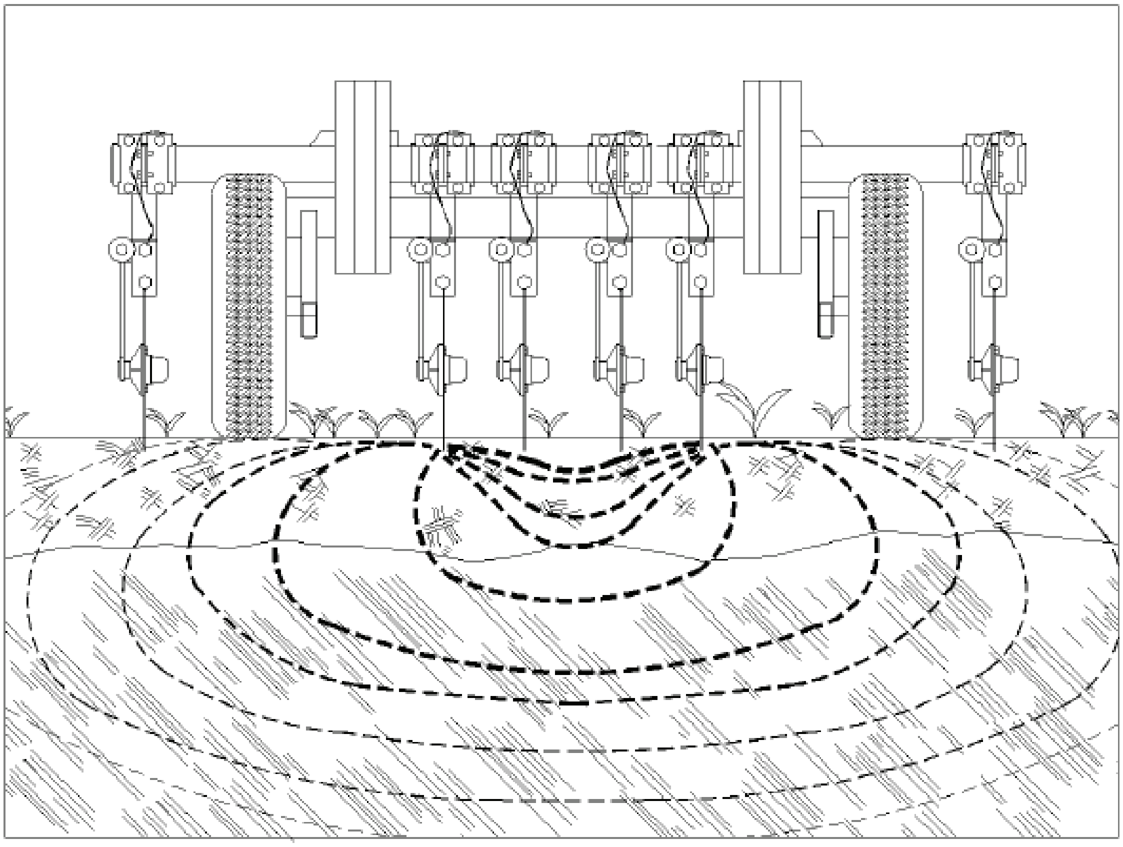


Figure 4. The Veris NIRS with soil conductivity mapping system uses two arrays to measure EC at two depths, 0-25 cm and 0-75 cm (Lund and Christy, 1998).

potential is measured at potential electrodes at specific distances from the current electrode as seen above. This distance determines the depth to which EC measurements are taken. The depth depends on the many soil characteristics including the soil structure and texture. Because this current travels through a large volume of the soil profile, the measured values reflect very well the bulk, or apparent, soil electrical conductivity.

Electrical conductivity measuring techniques for soils were developed in the 1920s by Conrad Schlumberger in France and Frank Wenner in the United States (Telford, 1990; Burger, 1992; Corwin and Lesch, 2005). The four equally-spaced

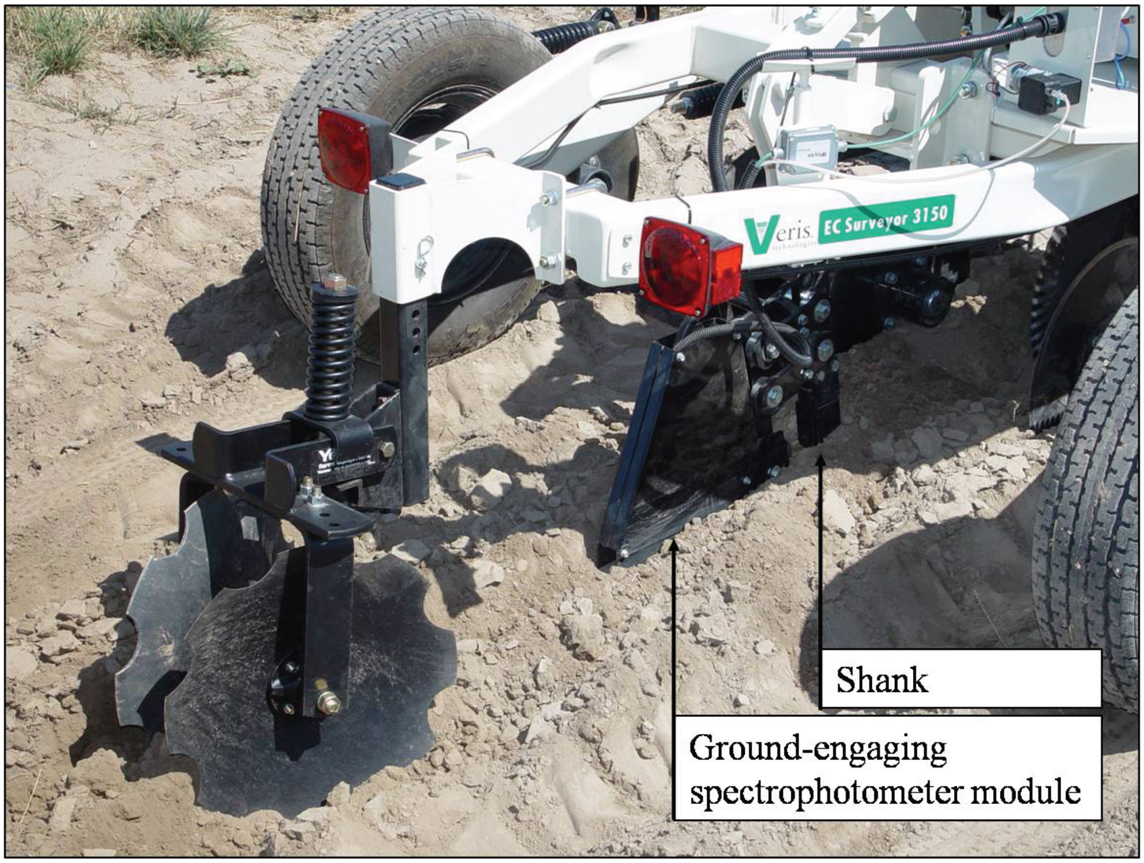


Figure 5. The Veris NIRS unit includes a ground-engaging spectrophotometer module that slides along the smooth skid of a 10 cm wide shank preceding it.

coulters configuration is commonly known as the Wenner array today. Since then, other configurations have been developed including that of the Veris NIRS instrument seen in the proceeding figures.

The Veris NIRS with EC Surveyor 3150 module carries both EC and spectral data collection equipment on board. The ground-engaging spectrophotometer module follows the cut of the shank and large diameter fluted coulter mounted immediately before it. The module consists of a light source, the lens to collect light that has interacted with the soil, and the spectrometer to measure the collected light. Reflectance measurements are taken through a durable sapphire window on the bottom of this module which slides along the skid created by the shank. Data is output as a text file with catalogued, georeferenced absorbance values for each wavelength in the measured spectrum.

While this particular instrument is relatively new, it merely combines two well-known technologies in a manner that allows synchronized measurement of soil properties. This combination is a powerful tool to qualitatively classify spatial variability of soils.

METHODS AND MATERIALS

STUDY AREAS

This study took place at three different Utah Agricultural Experiment Station farms that have different soil types representative of typical arable lands of the Intermountain West (Figure 6). The first location was the Greenville Research Farm, located in North Logan, Utah. The second location was the Evans Research Farm in Millville, Utah. Finally, the third farm was the Utah Botanical Center located in Kaysville, Utah.

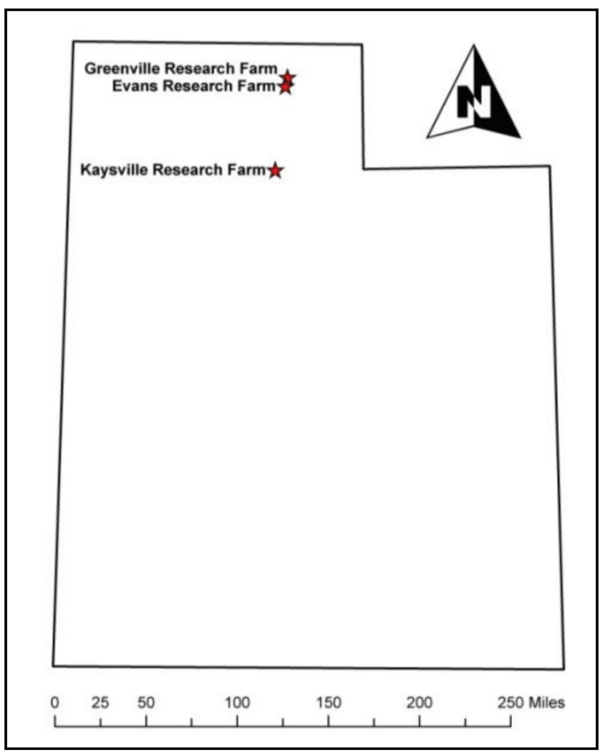


Figure 6. Location of Utah Agricultural Experiment Station farms involved in this study.

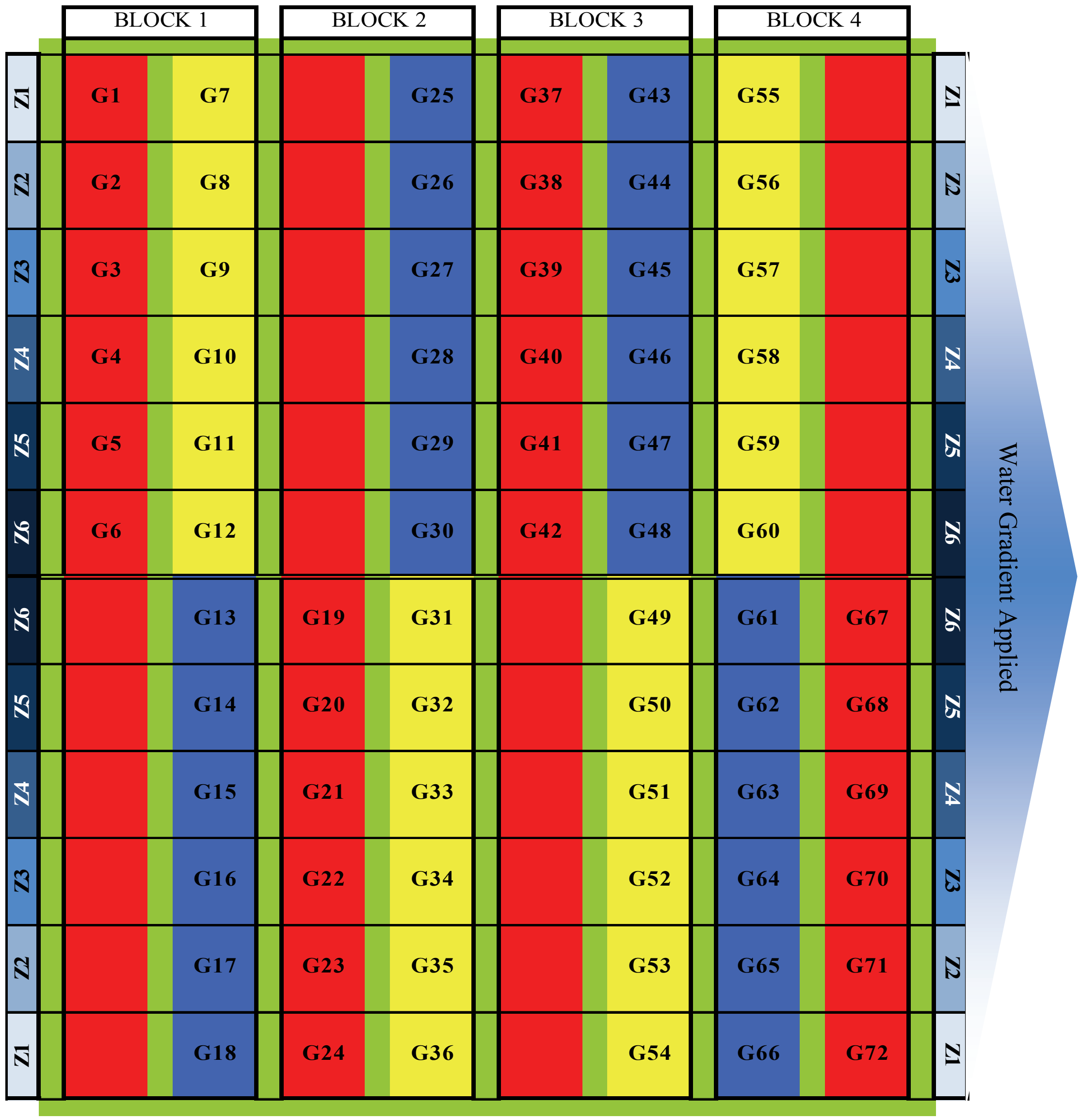
Soils at the Greenville Research Farm are Millville, coarse-silty, carbonatic, mesic Typic Haploxerolls (Soil Survey Staff, 2007). Here, we find the most coarse soil conditions of the three locations. At the Evans Research Farm, the soils are Nebeker, fine, montmorillonitic, mesic Pachic Argixerolls (Soil Survey Staff, 2007). These plots are composed of significantly finer soil than the other sites. Finally, soils at the Kaysville Research Farm are Kidman, coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls (Soil Survey Staff, 2007). The coarse-loamy soil is similar to those at the Greenville Farm, but has a slightly higher percentage of clays.

METHODS

Plots were created for this experiment to simulate high, medium, and low levels of compaction, soil water content, and coarseness of the soil. Dimensions were identical at all locations and were situated in a split-block design. The plots were bare soil strips 18.2 m (60 ft) long and 3 m (10 ft) wide. The entire area of each plot received one of three randomized compaction treatments creating high, medium, and low levels of compaction. The first treatment was used to relieve all possible compaction with a Miskin Parabolic Subsoiler (Ucon, Idaho) to a depth > 30.5 cm (12 in). Second, an induced compaction treatment was applied through tractor tire travel over the complete area of the plot with a Ford 1510 Tractor (Fargo, North Dakota) weighing 1036 kg (2285 lbs). Finally, an induced plowpan was created through repeated tillage with a Howard Rotavator HR7 (Sorø, Denmark) to a depth of 10 cm (4 in). All treatments were applied when soil moisture conditions were in unirrigated conditions during early August when soil and climatic conditions were dry.

After all treatments were applied, and shortly before data was collected, irrigation water was applied from one end of the plots using a line-source sprinkler method (Hanks et al., 1976), establishing a soil water gradient across the length of the plots. Each plot was divided into 6 water zones (Z1-Z6): Z6 being the wettest and nearest to the sprinklers, and Z1 being the furthest away and receiving virtually no irrigation.

This experimental plot layout (Figures 7-9) allows comparison between several different variables at one site and in one soil type. All of these factors potentially affect the null hypothesis.



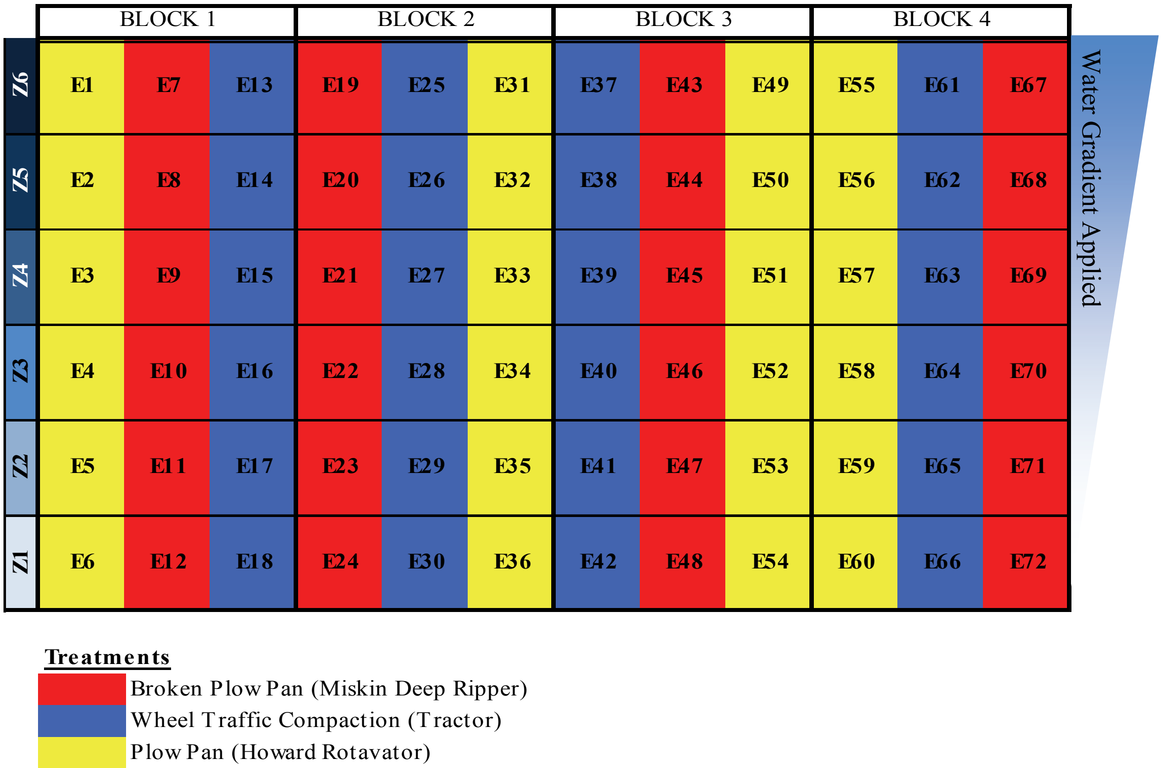
Treatments

Broken Plow Pan (Miskin Deep Ripper)
Wheel Traffic Compaction (Tractor)
Plow Pan (Howard Rotavator)
Grass Barrier

Measurements

1 Bulk Density core is taken in each plot
Shallow 5"-9" (12.7-22.9 cm)
Deep 11"-14" (27.9-38.1 cm)
1 Soil water content measurement taken in each plot
Shallow 5"-9" (12.7-22.9 cm)
Deep 11"-14" (27.9-38.1 cm)
ECa Measured with Veris NIRS
Tractor maintained in 2-2
Broad spectrum reflectance at 4 " (10 cm)
Penetration resistance at depth (SC 900)

Figure 7. Plot layout at the Greenville Research Farm.



Measurements

1 Bulk Density core is taken in each plot
- Shallow 5"-9" (12.7-22.9 cm)
- Deep 11"-14" (27.9-38.1 cm)

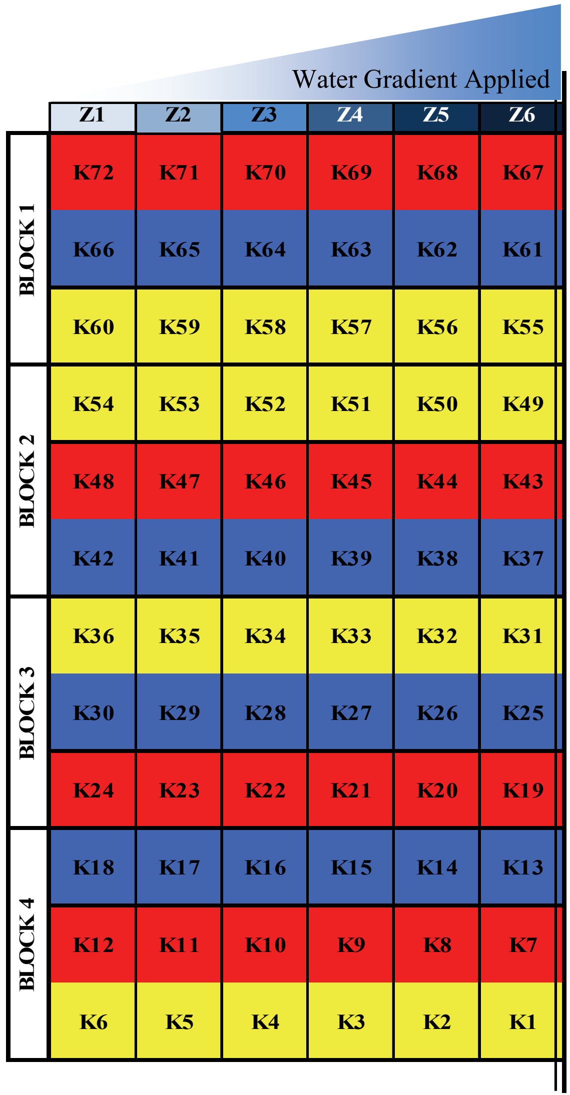
1 Soil water content measurement taken in each plot
- Shallow 5"-9" (12.7-22.9 cm)
- Deep 11"-14" (27.9-38.1 cm)

ECa Measured with Veris NIRS
- Tractor maintained in 2-2

Broad spectrum reflectance at 4 " (10 cm)

Penetration resistance at depth (SC 900)

Figure 8. Plot layout at the Evans Research Farm.



Treatments

Broken Plow Pan (Miskin Deep Ripper)
Wheel Traffic Compaction (Tractor)
Plow Pan (Howard Rotavator)

Measurements

1 Bulk Density core is taken in each plot
Shallow 5"-9" (12.7-22.9 cm)
Deep 11"-14" (27.9-38.1 cm)
1 Soil water content measurement taken in each plot
Shallow 5"-9" (12.7-22.9 cm)
Deep 11"-14" (27.9-38.1 cm)
ECa Measured with Veris NIRS
Tractor maintained in 2-2
Broad spectrum reflectance at 4 " (10 cm)
Penetration resistance at depth (SC 900)

Figure 9. Plot layout at the Kaysville Research Farm.

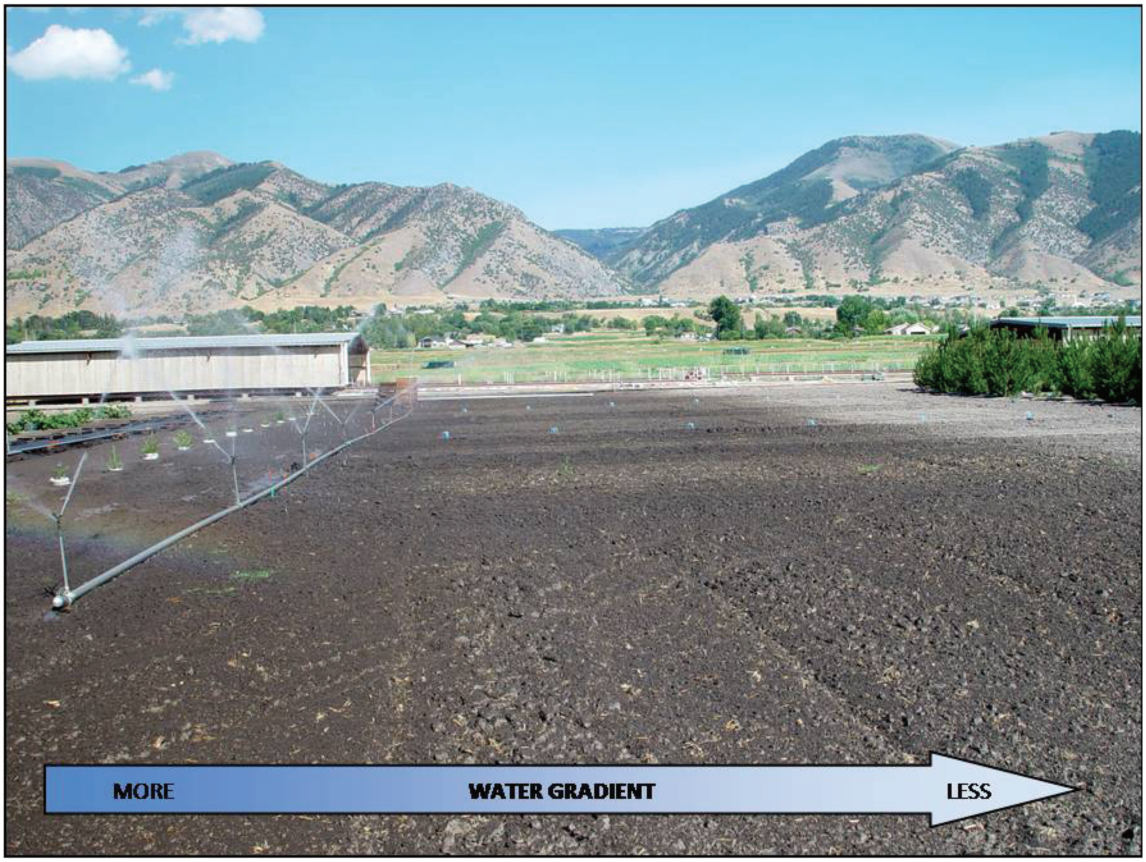


Figure 10. Line-source sprinkler method applying a differential water gradient over the six water zones across all tillage treatments at the Evans Research Farm.

The variables that are considered here are soil water content, the degree of compaction, and soil texture. A soil moisture gradient was created uniformly across all the plots (Figure 10). Within the plots, four sets of three different tillage treatments were induced. Finally, this same plot design was created at three different Utah State University Research Farms, each with a different soil texture.

Data collection began in late August 2007 and was completed in early September 2007. A period of 36 hours between the last irrigation and the beginning of sampling ensured the soil surface was not saturated both for sample integrity and ease of traveling over the plots with the sensors. Data collection started with simultaneous collection of shallow EC, deep EC, and reflectance data with the Veris NIRS instrument as outlined by the Veris Technologies Mobile Sensor Platform operation instructions. These instructions involved calibrating the spectrometer with the provided standards, initializing the GPS, checking that all systems were functioning properly, and finally traversing the plots with the EC coulters engaged with the soil from 3-5 cm deep and the spectrophotometer lowered to 10 cm. A continuous speed was maintained as the instrument measures and records EC, reflectance, and coordinate data every two seconds. Sampling was done traveling perpendicular to the length of the plots to group data into water zones.

Next, soil cores were taken at two depth ranges, 12.7–22.9 cm (5”- 9”) and 27.9–38.1 cm (11”- 15”). The Soil Survey Laboratory Procedures (Soil Survey Staff, 1996) were followed for bulk density and soil water content samples for each of the 72 plots at each site.

Finally, plot locations were recorded with a differentially corrected Trimble Pathfinder Pro XRS (Sunnyvale, California) GPS. Because EC and reflectance measurements are linked to coordinate data, they were easily displayed in a geographic information system (GIS) map using ArcGIS 9.2© (Redlands, California). Similarly, these GPS locations were also projected onto the map and used to group the EC and reflectance measurements with their corresponding plot numbers when displayed in ArcGIS 9.2© (Figure 11). Because several of these measured values exist within one plot, a summary database was created with the average shallow EC, deep EC, and reflectance value at 2151.9 nm for each plot.

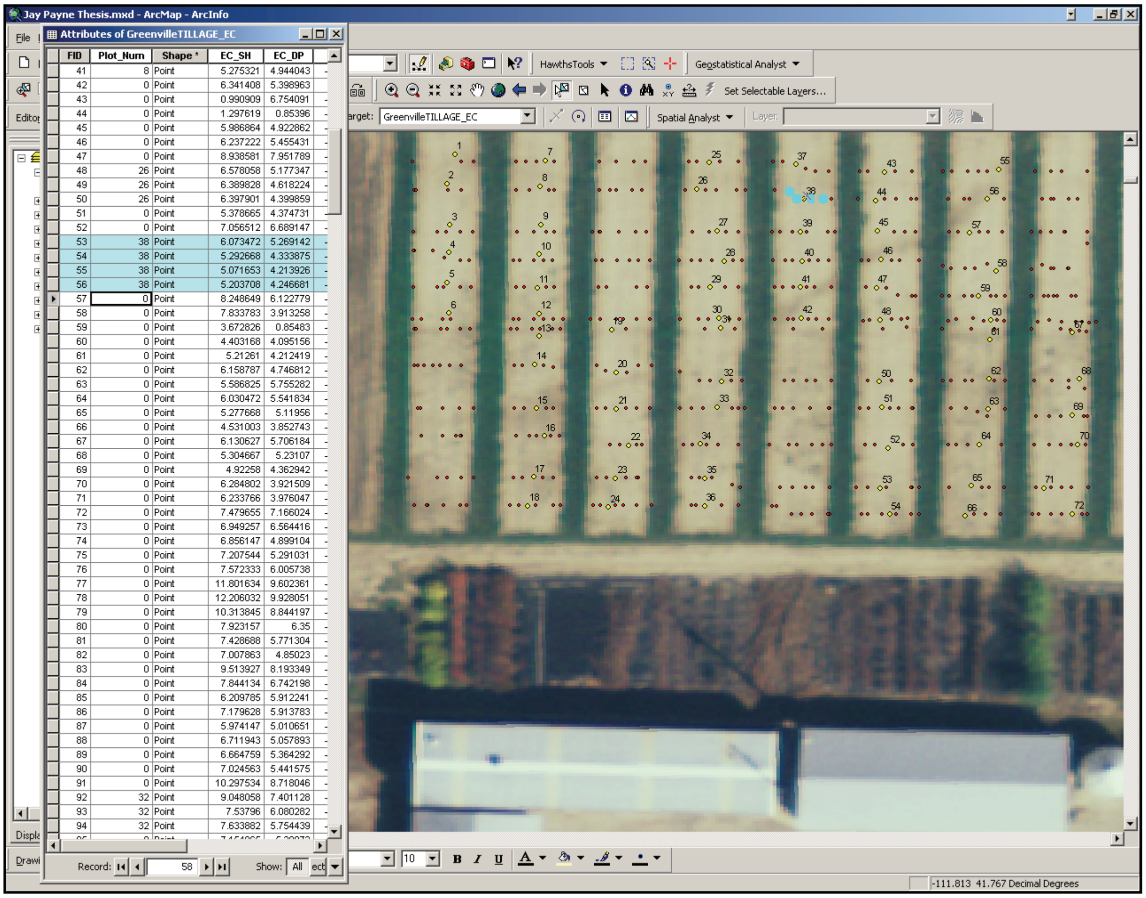


Figure 11. Assigning EC and reflectance measurements to plots through the use of ArcGIS 9.2©. Measurements are selected through geographic proximity to a GPS point taken in each plot, then are labeled by plot number accordingly.

Shallow and deep bulk density data were also added to the corresponding plot numbers. This allowed the researchers to choose the desired soil attributes to consider for regression analysis.

Identical plot design, procedures, and data management were followed at the Greenville, Evans, and Kaysville Research Farms. The Data Analysis Tool in Microsoft Excel 2007© was used to manage the data and perform statistical calculations. The regression function within the Data Analysis Tool generated several values for an analysis of variance (ANOVA) and analysis of regression including the F-value, probability level, and the r^2 value. An F-distribution table (Hayter, 2007) was also used for determining the threshold for F-test values at the 90 percent probability level. A confidence level of 90% was chosen to include as much relevant data as possible. An F-value of at least 49.50 is required to obtain significant results at the ($\alpha = 0.10$) 90% probability level (Hayter, 2007).

A successful F-test shows that there is sufficient distance between population means to produce significant regression results. In this case, the F-test values were used to test whether a difference existed between measured bulk density and EC (or reflectance) and warranted further analysis. The next step would then be to develop a regression equation. This analysis would produce an r^2 value that shows the strength of correlation between the variables being compared. When F-tests do not meet the threshold value, no further analysis can be done because there is not any significance between the recorded values.

RESULTS AND DISCUSSION

The primary objective of this research was to determine whether site-specific agricultural sensors measuring bulk soil electrical conductivity and near-infrared reflectance could be used to effectively identify subsoil compaction in the Intermountain West. ANOVA testing was used to determine whether a significant difference existed between the tillage, or compaction treatments as seen in Table 1. The F-value, which is a product of the ANOVA test, showed whether sufficient variance existed in the data, according to the degrees of freedom for the population, to achieve meaningful results from regression analysis. Significant variance was found between the induced compaction treatments and the control, or the deep ripped plots. This warrants further analysis because it was clear that there were differences in bulk density between the deep-ripped and compacted treatments.

Table 1. F-Test and threshold probability for significant bulk density between compaction treatments. (α = 0.10, degrees of freedom = 23, Means squared appear in appendix, * indicates significance)

	Greenville		**Evans**		**Kaysville**	
Bulk Density Shallow	Traffic	Plow Pan	Traffic	Plow Pan	Traffic	Plow Pan
Ripped F-Test	4.29*	13.41*	5.54*	2.24*	3.34*	2.12*
Ripped Probability	4.54E-04*	1.63E-08*	5.93E-05*	0.03*	2.72E-03*	0.04*
Bulk Density Deep						
Ripped F-Test	2.01*	0.05*	0.35	0.29	0.55	1.64
Ripped Probability	1.01	0.49	0.007*	0.001*	0.08*	0.12*

Next, ANOVA was used to discover whether a difference between bulk density values, shallow and deep EC, and NIR reflectance existed by category. Table 2 shows that all measurements grouped by category have sufficient variance one from another, and, once again, warranted further analysis between the water level, tillage treatment, and texture within the categories.

An ANOVA for all possible combinations of each of the 72 plots at all location showed how the treatments of each plot affected measured EC and reflectance values. The ANOVA results were based on three degrees of freedom, two from the treatment and one from the residual, or error, involved. Tables 3 through 5 show that only 34 of the 324 samples, slightly more than 10%, were within the 90% confidence interval. This data could not be interpreted to produce conclusive results because so few actually reached the significance threshold.

Table 2. One-way ANOVA of measurement categories without considering water or tillage treatments. (α = 0.10, degrees of freedom = 23,* indicates significance)

	Greenville		**Evans**		**Kaysville**	
	F-value	**P-value**	**F-value**	**P-value**	**F**	**P-value**
BDS_ECS	926.43*	1.43E-62*	392.50*	1.05E-42*	757.59*	8.65E-59*
BDS_ECD	795.19*	1.13E-58*	565.11*	2.35E-51*	1260.31*	1.72E-72*
BDS_REF	95.19*	1.40E-42*	54.98*	1.51E-23*	2103.24*	5.15E-87*
BDD_ECS	923.21*	1.76E-62*	394.67*	7.84E-43*	763.41*	5.47E-59*
BDD_ECD	791.33*	1.50E-58*	568.13*	1.74E-51*	1271.44*	9.78E-73*
BDD_REF	1752.67*	8.90E-82*	22.67*	5.08E-12*	135.90*	6.49E-51*
Threshold:	**F > 2.84**	**p < 0.10**	**F > 2.84**	**p < 0.10**	**F > 2.84**	**p < 0.10**

BDS= bulk density shallow; BDD= bulk density deep; ECS= electrical conductivity shallow; ECD= electrical conductivity deep; REF= near-infrared reflectance at 2151.9nm

Table 3. F-values for individual sub-plots at the Greenville Research Farm. The F-value threshold is set at F ≥ 49.50. Only 5 of the 108 combinations had significant results at the 90% confidence level. (* indicates significance, probability values, degrees of freedom and means squared are found in the appendices)

Soil: Millville, coarse-silty, carbonatic, mesic Typic Haploxerolls

		Bulk Density Shallow			Bulk Density Deep		
		1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow							
Water Zone	1 (dry)	0.21	4.31	4.65	11.14	4.96	0.72
	2	0.08	0.44	0.09	0.45	3.52	1.47
	3	0.95	1.35	0.12	0.96	1.41	4.24
	4	0.23	0.98	0.32	0.07	3.19	661.11*
	5	0.61	0.09	0.39	0.38	10.60	0.29
	6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A
EC Deep							
Water Zone	1 (dry)	1.00	2.79	1.82	16.65	3.19	0.29
	2	7.30	0.45	0.15	1.24	4.28	0.58
	3	11.00	2.72	0.24	20.90	1.01	41.21
	4	0.25	1.27	0.96	0.81	1.11	5.89
	5	0.44	0.31	0.32	0.45	403.57*	1.02
	6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A
NIR Reflectance							
Water Zone	1 (dry)	2.62	24.95	3.01	49.76*	24.32	0.54
	2	0.14	89.83*	0.39	0.04	9.31	354.82*
	3	0.01	0.13	18.57	0.01	0.98	0.93
	4	0.29	0.71	27.94	1.42	8.76	0.16
	5	2.78	0.46	43.08	0.02	21.46	4.75
	6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A

Table 4. F-values for individual sub-plots at the Evans Research Farm. The F-value threshold is set at F ≥ 49.50. Only 15 of the 108 combinations had significant results at the 90% confidence level. (* indicates significance, probability values, degrees of freedom and means squared are found in the appendices)

Soil: Nebeker, fine, montmorillonitic, mesic Pachic Argixerolls

		Bulk Density Shallow			Bulk Density Deep		
		1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow							
Water Zone	1 (dry)	0.11	3.15	4.84	1.40	25.03	10.23
	2	6.84	0.03	0.99	0.10	18.25	1.65
	3	0.81	61.75*	67.81*	0.01	2.46	3.76
	4	0.94	0.76	9674.58*	1.45	13.26	0.13
	5	16.89	0.55	5.66	0.67	0.39	0.74
	6 (wet)	37.31	1.38	1.48	20.26	1.30	1635.43*
EC Deep							
Water Zone	1 (dry)	11.73	0.86	1.38	427.37*	1.40	2.33
	2	0.57	0.95	196.79*	0.14	0.45	0.50
	3	0.54	34.07	0.48	0.04	5.60	0.99
	4	0.19	0.78	10.14	25.07	4.15	0.39
	5	755.03*	282.95*	6.02	0.24	40.21	0.65
	6 (wet)	5.14	0.38	1.32	53099.37*	0.40	2.91
NIR Reflectance							
Water Zone	1 (dry)	17.32	4.37	0.16	6.89	3.35	0.18
	2	793.05*	4.68	5.99	0.61	1.58	0.20
	3	182.47*	0.73	939.61*	4.38	10685.17*	0.90
	4	6.64	41.00	2.44	0.68	14.87	6.41
	5	7.26	0.56	0.19	0.76	0.40	1714.59*
	6 (wet)	0.60	5.22	0.92	51.49*	4.25	3.21

Table 5. F-values for individual sub-plots at the Kaysville Research Farm. The F-value threshold was set at F ≥ 49.50. Only 14 of the 108 combinations had significant results at the 90% confidence level. (* indicates significance, probability values, degrees of freedom and means squared are found in the appendices)

Soil: Kidman, coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls

		Bulk Density Shallow			Bulk Density Deep		
		1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow							
Water Zone	1 (dry)	48.50	0.69	79.76*	1.35	0.10	13.22
Water Zone	2	0.63	19.17	0.12	1.01	1.46	3.36
Water Zone	3	0.83	0.88	37.20	1.99	5.02	0.84
Water Zone	4	4.12	0.44	2.71	1.22	5013.24*	0.50
Water Zone	5	11.21	16.23	8.57	0.97	0.04	14.28
Water Zone	6 (wet)	23.59	4.03	1.60	6.79	75.23*	0.67
EC Deep							
Water Zone	1 (dry)	2.25	0.33	1.76	56.69*	0.63	5.98
Water Zone	2	4.70	0.09	5.29	2.41	1.46	59.41*
Water Zone	3	5.21	0.62	277.15*	697.01*	13.74	0.77
Water Zone	4	0.99	10.97	67559.76*	11.07	27.18	2.09
Water Zone	5	22.52	0.57	3.75	1.73	4.72	182.13*
Water Zone	6 (wet)	15614.76*	0.75	144.90*	12.88	0.39	4.02
NIR Reflectance							
Water Zone	1 (dry)	0.16	19.48	14411.35*	1.55	0.22	19.50
Water Zone	2	0.97	0.50	0.80	1.75	418.31*	19.64
Water Zone	3	0.15	96.14*	1.88	8.49	6.65	10.98
Water Zone	4	9.62	0.17	9.86	0.57	6.49	0.09
Water Zone	5	0.33	1.96	0.17	8.55	0.47	0.65
Water Zone	6 (wet)	1.57	0.28	13.60	0.19	0.51	47.10

The null hypothesis must be accepted. There is no apparent, statistically reliable evidence from this study to prove a relation between measured values of electrical conductivity and soil bulk density, or near-infrared reflectance and soil bulk density. Because the analysis of variance for the individual subplots rarely produced significant data, further investigation would probably not be significant. However, although a correlation was not found, this information builds a further understanding regarding the extent of effectiveness when using EC and NIRS in precision agriculture to classifying soil characteristics.

What was not previously understood has been tested and explained. The low-moisture soils, at levels typical to dry in-field levels, did not show that electricity preferentially follows the pathway of compacted soil particles over the liquid conductive pathway. Electrical conductivity will continue to correlate strongly with soil moisture and texture, but not compacted soil layers.

It has been shown that a minimum level of compaction was required before compacted conditions could be identified with EC or NIRS under typical field conditions in Utah. No significant EC data was collected that identified a difference between compacted and non-compacted soils under normal field conditions.

Soil texture did not influence whether significant results were obtainable using EC or NIRS. None of the three locations have more than 15% of the samples taken with a significant difference in measured values. This is not sufficient to infer that EC or NIRS correlates to bulk density stronger in one soil texture than another.

Finally, reflectance values at 2151.9 nm did not correlate to areas of known subsoil compaction. No significant difference was shown between reflectance of compacted soil and normal soil as measured by this method. Part of the reason for this was that the measurements were taken from the bottom of a skid sliding along the path created by a 10 cm (2 in) wide shank. Such a blade will cause a compacted layer where it comes in contact with the soil. Consequentially, all the soil measured by this NIRS instrument was possibly compacted as the measurements were recorded. Further efforts to use NIRS to identify compacted soils would be limited to surface measurements where soil properties are not affected by ground engaging sensors.

Of the 34 samples that were found to be significant, there is a meaningful pattern. Histograms showing the occurrence of significant measurements by category show that there is a small difference between number of significant samples between the compaction, water content, and location (soil texture) variables. See the Appendices (Tables 6-8) for actual graphs. This data is not statistically significant and only mentioned to better understand possible underlying contributing factors. This data only suggests that a very small portion of the electrical pathway is influenced by either location (soil texture) or soil water content.

Data collected in this research, while not statistically significant, suggests that the ability to correlate EC and NIRS with bulk density in soil is better in dry soils, rather than wet soils. This speculation stems from a higher average occurrence of significant samples in the three drier water zones (Z1 - Z3) than the three wetter zones (Z4 - Z6). It also suggests that the soil texture, which varied by location, also influences the ability to correlate with bulk density. Three times more significant results occurred at the Evans and Kaysville Research Farms than at the Greenville Research Farm. Both the Evans and Kaysville Research Farm soils contain considerably more clay than the soil found on the

Greenville Research Farm. As opposed to the original hypothesis, it appears that coarse-textured soils are not better indicators of soil compaction due to their lack of inherent conductivity. Soils that have a clay component are more likely to show a correlation between either EC or NIRS and bulk density.

CONCLUSIONS

Subsoil compaction can severely limit crop yield potential. Treatment of compacted soil involves considerable financial, energy, and labor investments. Further, blanket treatment of fields in an effort to relieve soil compaction is inefficient and leads to increased soil erosion and loss of soil organic matter. Site-specific agriculture technology that accurately identifies these layers could prescribe tillage practices to affected areas only, thus preventing unnecessary intervention to entire fields.

Bulk electrical conductivity (EC) through the bulk soil is an excellent indicator of spatial variability due to a complex and interrelated group of physical and chemical soil attributes. While EC has been found to correlate to many different soil attributes, this study found that EC did not correlate to subsoil compaction under normal field conditions in the Intermountain West. Theories that claim electrical conductivity (through particle-to-particle contact) is measurable are not substantiated by these in-field studies. Neither soil water content levels, certain soil textures, nor a particular level of compaction caused EC (through particle-to-particle contact) to dominate other conductive pathways of the bulk soil profile.

Near-infrared reflectance (NIR) can also be an effective tool to indicate spatial variability of soil attributes. However, in this study, NIRS using a 2151.9 nm wavelength was not an indicator of compacted subsoil conditions. Like EC, NIRS's ability to predict subsoil compaction is not significantly affected by moisture, degree of compaction, nor soil texture for in-field studies. Large, ground-engaging sensors cause the physical properties of the soil to change and therefore cannot be used to measure compaction.

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APPENDIX

Table 6. Histogram of Significant Samples by Water Zone (Z1-Z6) Indiscriminate of Other Variables at $\alpha = 0.10$, $F \geq 49.50$

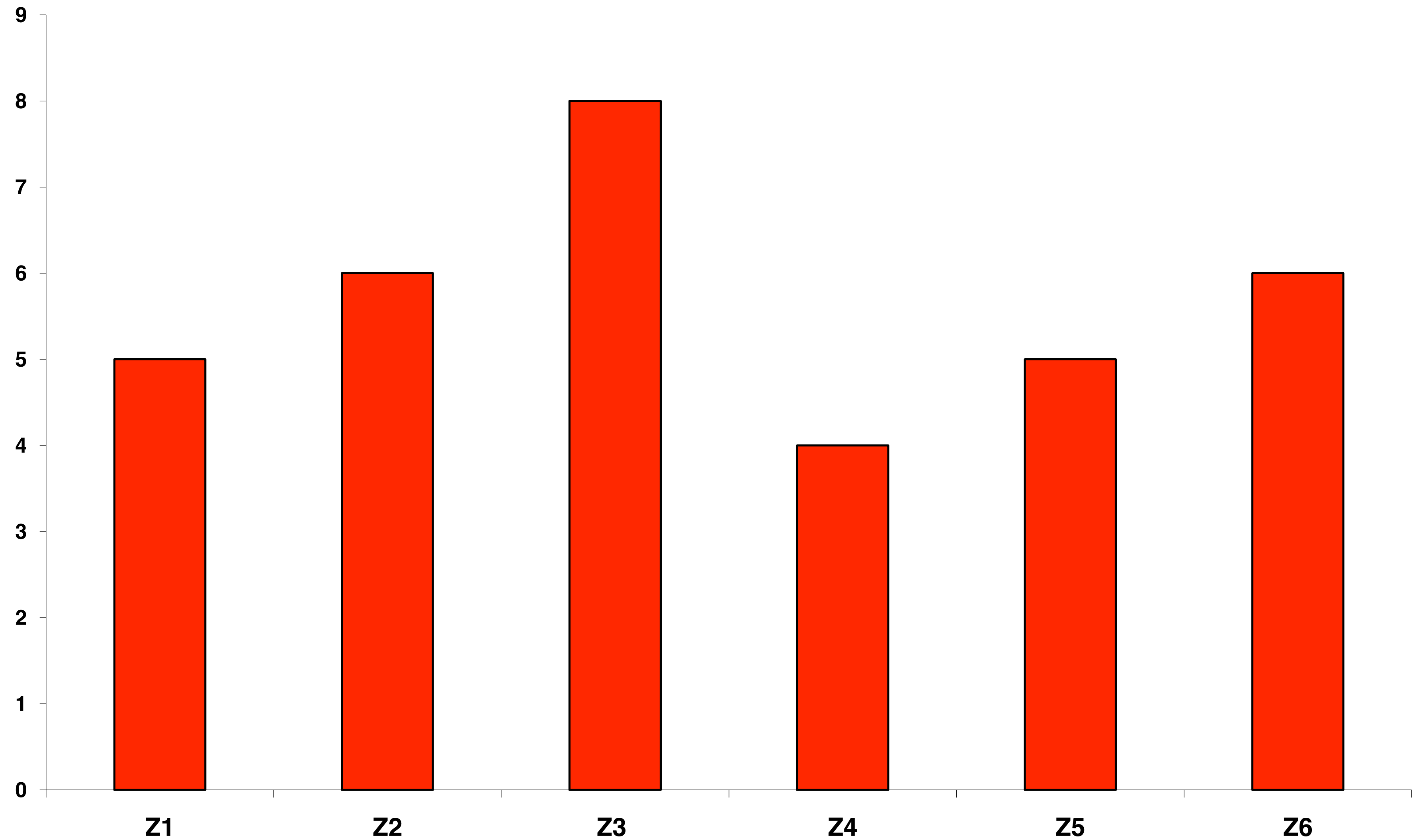


Table 7. Histogram of Significant Samples by Tillage Treatment Indiscriminate of Other Variables at $\alpha = 0.10$, $F \geq 49.50$

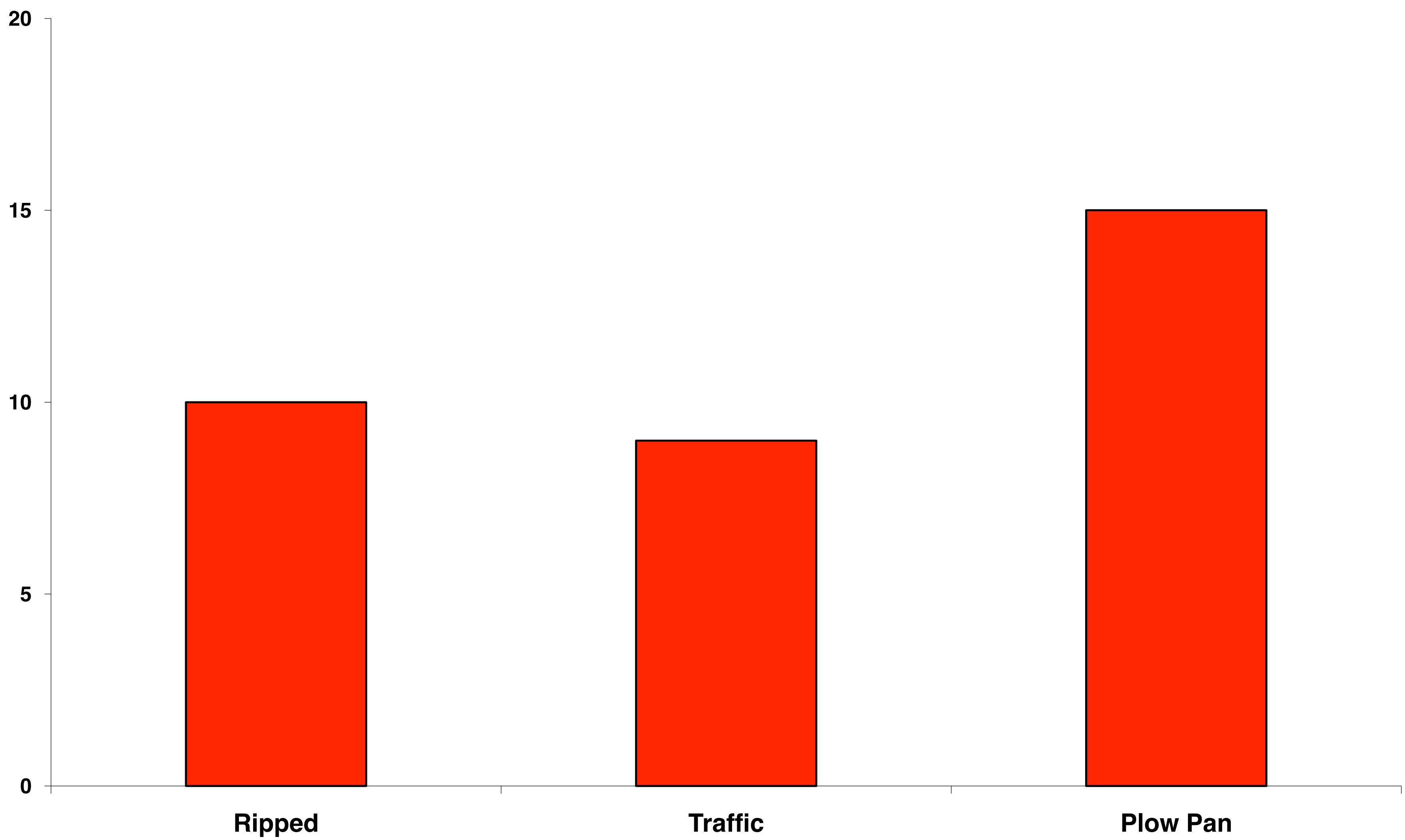


Table 8. Histogram of Significant Samples by Soil Texture Indiscriminate of Other Variables at $\alpha = 0.20$

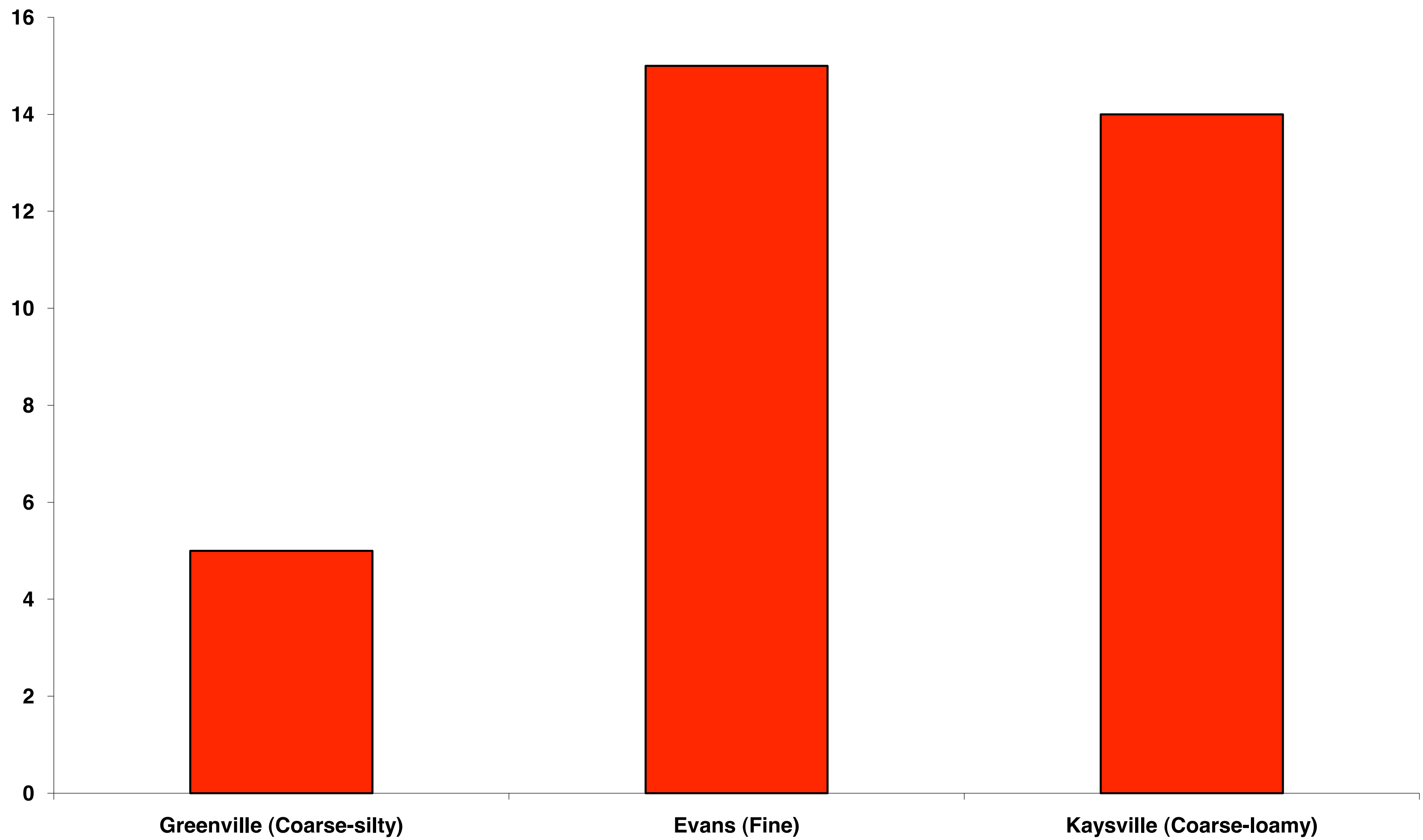


Table 9. Greenville F-Test (Two-Sample) for Variances between Bulk Density for Compaction Treatment vs. Control Table 1 Values

	S Ripped	*S Wheel*
Mean	1.66363164	1.829708657
Mean squared	2.767670235	3.347833771
Variance	0.013843654	0.003229322
Observations	24	24
df	23	23
F	4.286860778	
P(F<=f) one-tail	0.000454057	
F Critical one-tail	1.427230481	

	S Ripped	*S PlowPan*
Mean	1.66363164	1.766286865
Mean squared	2.767670235	3.119769289
Variance	0.013843654	0.001032138
Observations	24	24
df	23	23
F	13.41260532	
P(F<=f) one-tail	1.63438E-08	
F Critical one-tail	1.427230481	

	S Wheel	*S PlowPan*
Mean	1.829708657	1.766286865
Mean squared	3.347833771	3.119769289
Variance	0.003229322	0.001032138
Observations	24	24
df	23	23
F	3.128770915	
P(F<=f) one-tail	0.004170526	
F Critical one-tail	1.427230481	

	D Ripped	*D Wheel*
Mean	1.740354796	1.74802264
Mean squared	3.028834816	3.055583151
Variance	0.017456618	0.008666065
Observations	24	24
df	23	23
F	2.014364978	
P(F<=f) one-tail	0.05000706	
F Critical one-tail	1.427230481	

	D Ripped	*D PlowPan*
Mean	1.740354796	1.782293211
Mean squared	3.028834816	3.176569089
Variance	0.017456618	0.017364645
Observations	24	24
df	23	23
F	1.005296581	
P(F<=f) one-tail	0.495001251	
F Critical one-tail	1.427230481	

	D Wheel	*D PlowPan*
Mean	1.74802264	1.782293211
Mean squared	3.055583151	3.176569089
Variance	0.008666065	0.017364645
Observations	24	24
df	23	23
F	0.499063771	
P(F<=f) one-tail	0.051274956	
F Critical one-tail	0.700657681	

Table 10. Greenville Research Farm ANOVA Data for Table 2

Bulk Density Shallow and EC Shallow

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	126.23	1.75	0.01
Column 2	66.00	453.79	6.88	2.03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	903.53	1.00	903.53	926.43	0.00	3.91
Within Groups	132.64	136.00	0.98			
Total	1036.16	137.00				

Bulk Density Shallow and EC Deep

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	66.00	374.07	5.67	1.38
Column 2	72.00	126.23	1.75	0.01

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	527.65	1.00	527.65	795.19	0.00	3.91
Within Groups	90.24	136.00	0.66			
Total	617.89	137.00				

Bulk Density Shallow and Reflectance

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	126.23	1.75	0.01
Column 2	71.00	93973.00	1323.56	1202573.02
Column 3	71.00	109759.00	1545.90	894595.40
Column 4	72.00	56.48	0.78	0.02

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	148667236.28	3.00	49555745.43	95.19	0.00	2.64
Within Groups	146801792.26	282.00	520573.73			
Total	295469028.54	285.00				

Bulk Density Deep and EC Shallow

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	66.00	453.79	6.88	2.03
Column 2	72.00	126.50	1.76	0.01

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	902.23	1.00	902.23	923.21	0.00	3.91
Within Groups	132.91	136.00	0.98			
Total	1035.14	137.00				

Bulk Density Deep and EC Deep

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	126.50	1.76	0.01
Column 2	66.00	374.07	5.67	1.38

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	526.66	1.00	526.66	791.33	0.00	3.91
Within Groups	90.51	136.00	0.67			
Total	617.17	137.00				

Bulk Density Deep and Reflectance

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	56.48	0.78	0.02
Column 2	72.00	126.50	1.76	0.01

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	34.04	1.00	34.04	1752.67	0.00	3.91
Within Groups	2.76	142.00	0.02			
Total	36.80	143.00				

Table 11. Correlation Betwen Shallow Bulk Density and Shallow Electrical Conductivity at the Greenville Research Farm

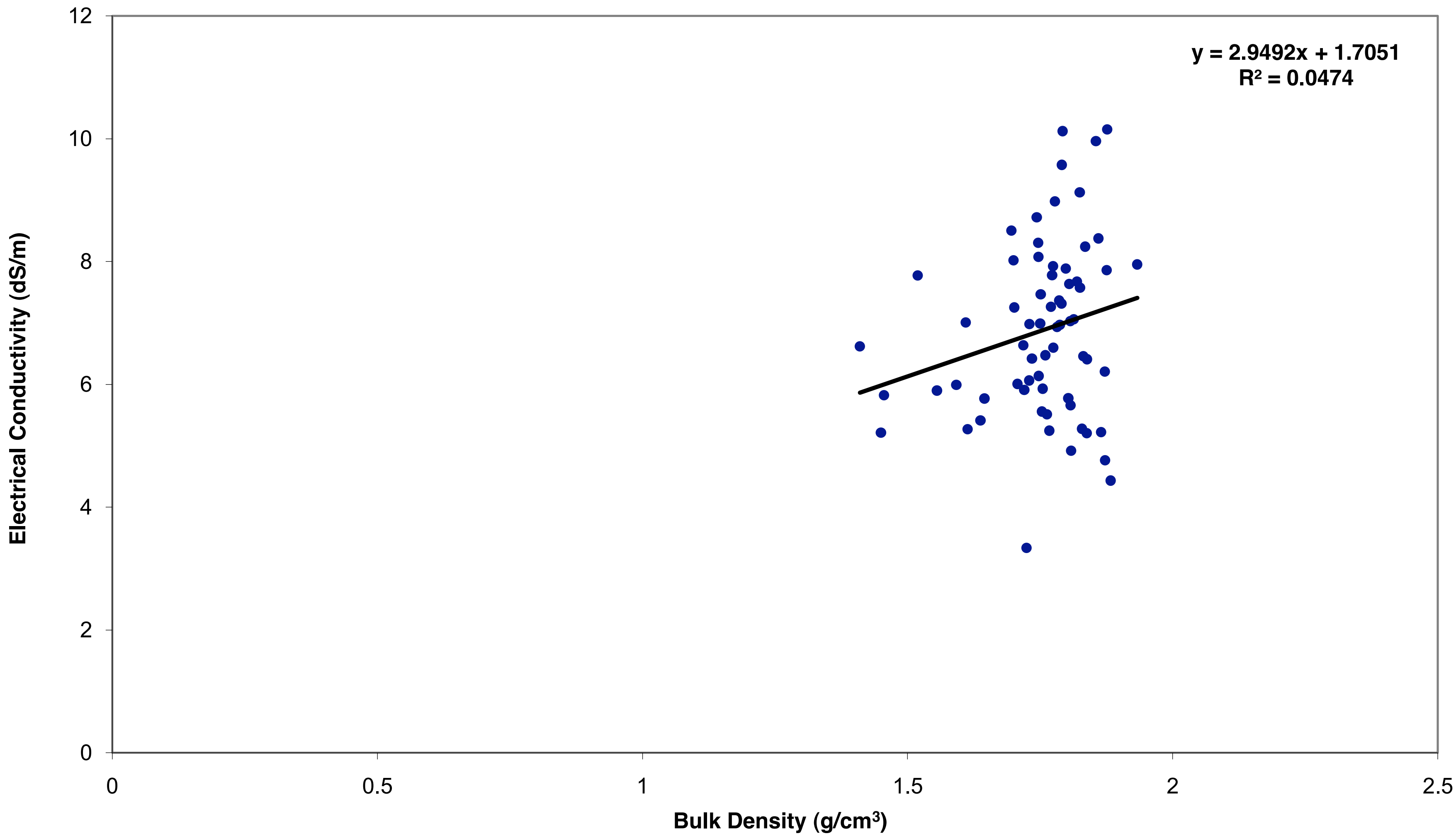


Table 12. Evans F-Test (Two-Sample) for Variances between Bulk Density for Compaction Treatment vs. Control Table 1 Values

	S Ripped	*S Wheel*
Mean	1.269218286	1.675904663
Mean squared	1.610915057	2.808656438
Variance	0.09724648	0.01755503
Observations	24	24
df	23	23
F	5.539522177	
P(F<=f) one-tail	5.92666E-05	
F Critical one-tail	1.427230481	

	S Ripped	*S PlowPan*
Mean	1.269218286	1.60376433
Mean squared	1.610915057	2.572060025
Variance	0.09724648	0.04328838
Observations	24	24
df	23	23
F	2.246479972	
P(F<=f) one-tail	0.029058391	
F Critical one-tail	1.427230481	

	S Wheel	*S PlowPan*
Mean	1.675904663	1.60376433
Mean squared	2.808656438	2.572060025
Variance	0.01755503	0.04328838
Observations	24	24
df	23	23
F	0.405536777	
P(F<=f) one-tail	0.017582066	
F Critical one-tail	0.700657681	

	D Ripped	*D Wheel*
Mean	1.365792887	1.325016944
Mean squared	1.86539021	1.755669902
Variance	0.04634633	0.132332444
Observations	24	24
df	23	23
F	0.350226508	
P(F<=f) one-tail	0.007436619	
F Critical one-tail	0.700657681	

	D Ripped	*D PlowPan*
Mean	1.365792887	1.366687096
Mean squared	1.86539021	1.867833619
Variance	0.04634633	0.161893748
Observations	24	24
df	23	23
F	0.286276219	
P(F<=f) one-tail	0.001995598	
F Critical one-tail	0.700657681	

	D Wheel	*D PlowPan*
Mean	1.325016944	1.366687096
Mean squared	1.755669902	1.867833619
Variance	0.132332444	0.161893748
Observations	24	24
df	23	23
F	0.817403057	
P(F<=f) one-tail	0.316378418	
F Critical one-tail	0.700657681	

Table 13. Evans Research Farm ANOVA Data for Table 2

Bulk Density Shallow and EC Shallow

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	109.17	1.52	0.08
Column 2	72.00	4359.50	60.55	639.17

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	125453.02	1.00	125453.02	392.50	0.00	3.91
Within Groups	45386.70	142.00	319.62			
Total	170839.72	143.00				

Bulk Density Shallow and EC Deep

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72	109.173	1.5162958	0.083045
Column 2	72	4471.67	62.106459	467.6583

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	132162.05	1	132162.05	565.1074	2.4E-51	3.908
Within Groups	33209.634	142	233.87066			
Total	165371.68	143				

Bulk Density Shallow and Reflectance

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72	109.173	1.5162958	0.083045
Column 2	72	69.1162	0.9599479	0.050163

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.142827	3	3.7142757	54.98116	1.5E-23	2.669
Within Groups	9.4577595	140	0.0675554			
Total	20.600587	143				

Bulk Density Deep and EC Shallow

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72	97.3799	1.352499	0.110709
Column 2	72	4359.5	60.548543	639.1662

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	126150.18	1	126150.18	394.6652	7.8E-43	3.908
Within Groups	45388.66	142	319.63845			
Total	171538.84	143				

Bulk Density Deep and EC Deep

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	97.38	1.35	0.11
Column 2	72.00	4471.67	62.11	467.66

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	132877.57	1.00	132877.57	568.13	0.00	3.91
Within Groups	33211.60	142.00	233.88			
Total	166089.17	143.00				

Bulk Density Deep and Reflectance

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72	97.3799	1.352499	0.110709
Column 2	72	69.1162	0.9599479	0.050163

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.5474694	3	1.8491565	22.66539	5.1E-12	2.669
Within Groups	11.421906	140	0.081585			
Total	16.969376	143				

Table 14. Correlation Between Shallow Bulk Density and Shallow Electrical Conductivity at the Evans Research Farm

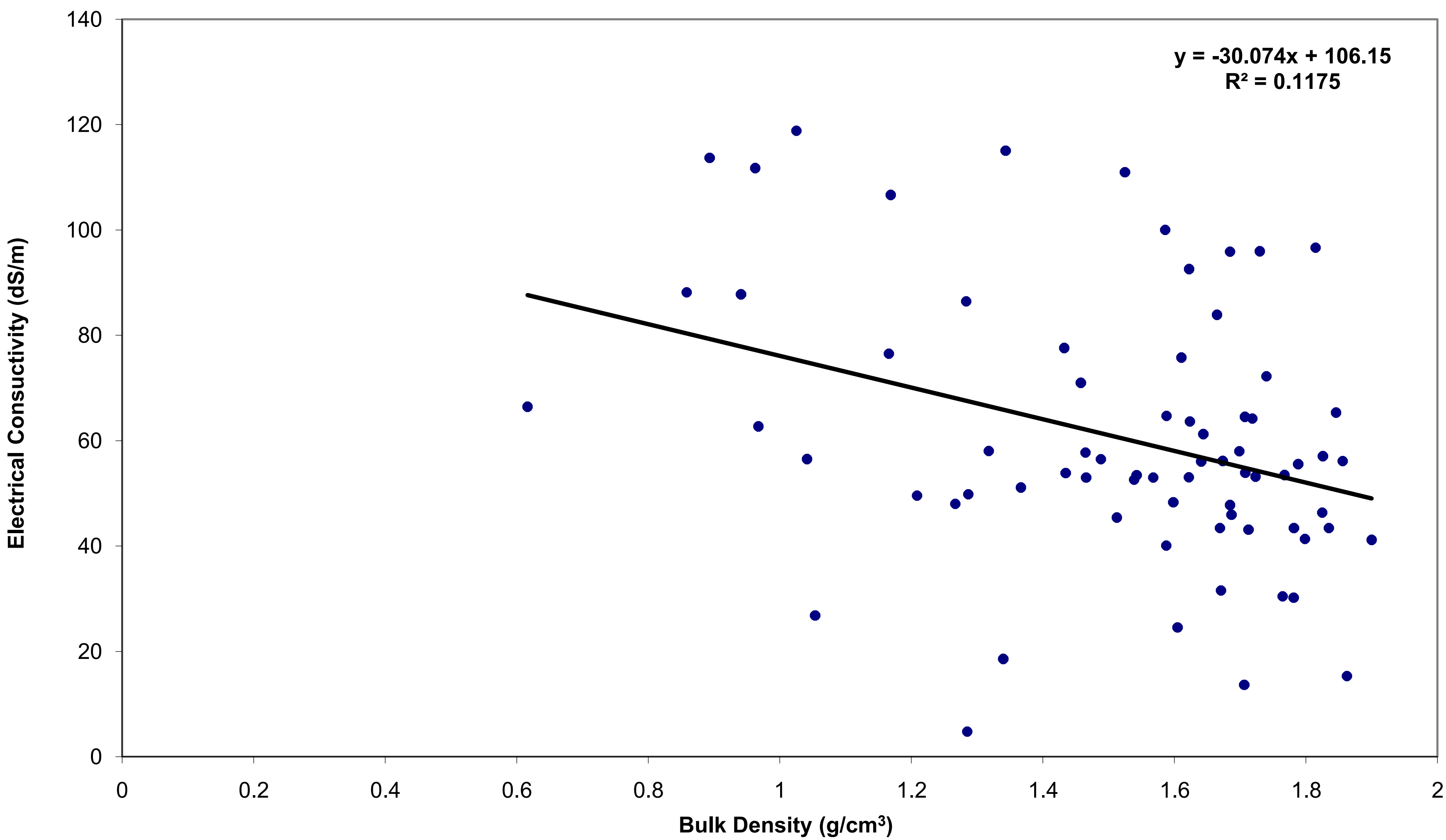


Table 15. Kaysville F-Test (Two-Sample) for Variances between Bulk Density for Compaction Treatment vs. Control Table 1 Values

	S Ripped	*S Wheel*
Mean	1.790318739	1.90902502
Mean squared	3.205241187	3.644376526
Variance	0.027991508	0.008387513
Observations	24	24
df	23	23
F	3.337283432	
P(F<=f) one-tail	0.002722608	
F Critical one-tail	1.427230481	

	S Ripped	*S PlowPan*
Mean	1.790318739	1.967416885
Mean squared	3.205241187	3.870729201
Variance	0.027991508	0.013219254
Observations	24	24
df	23	23
F	2.1174801	
P(F<=f) one-tail	0.039243642	
F Critical one-tail	1.427230481	

	S Wheel	*S PlowPan*
Mean	1.90902502	1.967416885
Mean squared	3.644376526	3.870729201
Variance	0.008387513	0.013219254
Observations	24	24
df	23	23
F	0.634492138	
P(F<=f) one-tail	0.141288834	
F Critical one-tail	0.700657681	

	D Ripped	*D Wheel*
Mean	1.776145522	1.791258679
Mean squared	3.154692915	3.208607656
Variance	0.025459962	0.046126998
Observations	24	24
df	23	23
F	0.551953578	
P(F<=f) one-tail	0.080816415	
F Critical one-tail	0.700657681	

	D Ripped	*D PlowPan*
Mean	1.776145522	1.857719763
Mean squared	3.154692915	3.451122717
Variance	0.025459962	0.015540518
Observations	24	24
df	23	23
F	1.638295577	
P(F<=f) one-tail	0.121978421	
F Critical one-tail	1.427230481	

	D Wheel	*D PlowPan*
Mean	1.791258679	1.857719763
Mean squared	3.208607656	3.451122717
Variance	0.046126998	0.015540518
Observations	24	24
df	23	23
F	2.968176389	
P(F<=f) one-tail	0.005841892	
F Critical one-tail	1.427230481	

Table 16. Kaysville Research Farm ANOVA Data for Table 2

Bulk Density Shallow and EC Shallow

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	136.00	1.89	0.02
Column 2	72.00	1610.31	22.37	39.83

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15094.41	1.00	15094.41	757.59	0.00	3.91
Within Groups	2829.23	142.00	19.92			
Total	17923.64	143.00				

Bulk Density Shallow and EC Deep

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	136.00	1.89	0.02
Column 2	72.00	1387.44	19.27	17.24

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10875.63	1.00	10875.63	1260.31	0.00	3.91
Within Groups	1225.36	142.00	8.63			
Total	12100.99	143.00				

Bulk Density Shallow and Reflectance

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	136.00	1.89	0.02
Column 2	72.00	51.84	0.72	0.03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	49.18	1.00	49.18	2103.24	0.00	3.91
Within Groups	3.32	142.00	0.02			
Total	52.51	143.00				

Bulk Density Deep and EC Shallow

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	1610.31	22.37	39.83
Column 2	72.00	130.20	1.81	0.03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15213.39	1.00	15213.39	763.41	0.00	3.91
Within Groups	2829.80	142.00	19.93			
Total	18043.19	143.00				

Bulk Density Deep and EC Deep

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	130.20	1.81	0.03
Column 2	72.00	1387.44	19.27	17.24

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10976.66	1.00	10976.66	1271.44	0.00	3.91
Within Groups	1225.92	142.00	8.63			
Total	12202.58	143.00				

Bulk Density Deep and Reflectance

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	72.00	130.20	1.81	0.03
Column 2	50.00	88001.00	1760.02	1609007.90
Column 3	43.00	106214.00	2470.09	1630638.75
Column 4	72.00	51.84	0.72	0.03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	257789882.48	3.00	85929960.83	135.90	0.00	2.64
Within Groups	147328218.49	233.00	632309.95			
Total	405118100.97	236.00				

Table 17. Correlation Between Shallow Bulk Density and Shallow Electrical Conductivity at the Kaysville Research Farm

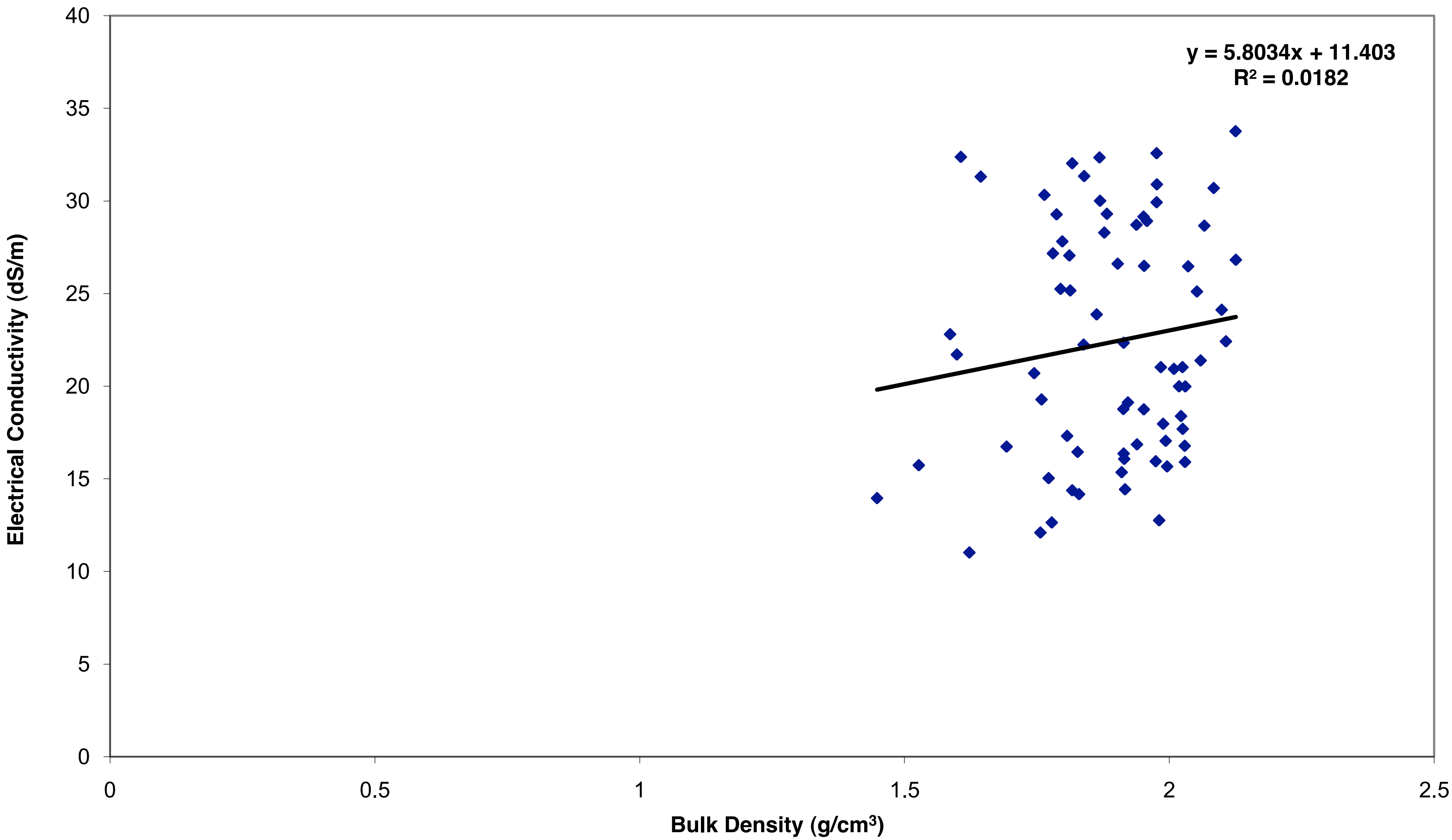


Table 18. Greenville Tillage Statistics

1	No Compaction
2	Wheel Traffic
3	Plow Pan

Plot	Till Treat	Wat Zone	BD_Shal	BD_Deep	EC_Shal	EC_Deep	Refl_2151.9
1	1	1	1.83	1.67	5.27	4.01	0.8444
2	1	2	1.75	1.70	5.93	4.38	0.8154
3	1	3	1.75	1.78	6.13	4.80	0.8630
4	1	4	1.72	1.88	6.63	5.78	0.4797
5	1	5	1.78	1.78	6.93	5.53	0.5822
6	1	6	1.70	1.64	8.02	5.98	0.7694
7	3	1	1.76	1.63	5.51	4.47	0.7380
8	3	2	1.75	1.78	5.55	5.28	0.7767
9	3	3	1.77	1.89	6.59	5.27	0.8561
10	3	4	1.70	1.88	7.25	6.05	0.7806
11	3	5	1.80	1.79	7.88	5.76	1.0496
12	3	6	1.75	1.85	8.30	6.27	0.9449
13	2	6	1.91	1.81			0.9606
14	2	5	1.70	1.68	8.50	6.33	0.9411
15	2	4	1.81	1.76	7.06	5.18	0.7415
16	2	3	1.82	1.85	9.12	7.29	0.6067
17	2	2	1.86	1.87	9.96	8.07	0.7624
18	2	1	1.77	1.58	7.92	7.28	0.6487
19	1	6	1.71	1.67			0.7051
20	1	5	1.45	1.76	5.21	4.31	1.2183
21	1	4	1.41	1.77	6.62	5.52	0.6469
22	1	3	1.56	1.68	5.90	5.46	0.7647
23	1	2	1.46	1.40	5.82	5.52	0.7986
24	1	1	1.79	1.82	7.31	6.06	0.6628
25	2	1	1.87	1.85	4.76	4.62	0.5094
26	2	2	1.83	1.77	6.46	4.73	0.8003
27	2	3	1.84	1.75	6.41	5.25	0.7925
28	2	4	1.83	1.87	8.24	6.07	0.8610
29	2	5	1.88	1.62	7.86	6.31	0.9400
30	2	6	1.93	1.69	7.95	6.27	0.8249
31	3	6	1.74	1.94			0.8845
32	3	5	1.75	1.90	8.07	6.41	0.7008
33	3	4	1.75	1.78	7.46	5.84	0.9328
34	3	3	1.75	1.68	6.99	6.38	0.5136
35	3	2	1.77	1.80	7.77	6.63	1.1278
36	3	1	1.79	1.79	6.97	6.93	0.4947
37	1	1	1.77	1.77	5.24	4.45	0.4763
38	1	2	1.64	1.96	5.41	4.52	0.8646
39	1	3	1.61	1.54	5.27	4.49	1.0267
40	1	4	1.71	1.92	6.00	4.87	0.9281
41	1	5	1.72	1.71	5.91	4.70	0.8848
42	1	6	1.52	1.88	7.77	6.28	0.8233
43	2	1	1.84	1.76	5.20	4.01	0.7886
44	2	2	1.88	1.77	4.43	3.05	0.7925
45	2	3	1.86	1.68	5.22	3.78	0.6862
46	2	4	1.87	1.73	6.20	4.85	0.6519
47	2	5	1.86	1.61	8.37	6.30	0.9503

Greenville Tillage Statistics

1 No Compaction
2 Wheel Traffic
3 Plow Pan

Plot	Till Treat	Wat Zone	BD_Shal	BD_Deep	EC_Shal	EC_Deep	Refl_2151.9
48	2	6	1.74	1.86	8.72	6.62	0.7876
49	3	6	1.75	1.66			0.8687
50	3	5	1.81	1.83	7.03	6.33	0.9507
51	3	4	1.82	1.81	7.67	6.22	0.6022
52	3	3	1.77	1.68	7.26	6.22	0.7257
53	3	2	1.73	1.78	6.98	6.58	0.8147
54	3	1	1.80	1.41	5.77	5.44	0.6829
55	3	1	1.72	1.94	3.33	2.83	1.0150
56	3	2	1.81	2.09	5.65	5.33	0.7296
57	3	3	1.76	1.73	6.47	5.52	0.6202
58	3	4	1.73	1.71	6.42	5.37	0.8751
59	3	5	1.83	1.75	7.57	5.93	0.7530
60	3	6	1.78	1.69	8.98	7.69	0.4957
61	2	6	1.74	1.59			0.8393
62	2	5	1.88	1.78	10.15	8.37	0.8804
63	2	4	1.79	1.87	9.57	8.08	0.8089
64	2	3	1.79	1.70	7.36	6.09	0.6374
65	2	2	1.79	1.85	10.12	8.59	0.9233
66	2	1	1.80	1.66	7.63	6.52	0.8799
67	1	6	1.67	1.71			0.7740
68	1	5	1.61	1.84	7.00	5.58	0.8279
69	1	4	1.73	1.79	6.06	5.37	0.6536
70	1	3	1.64	1.53	5.77	4.50	0.5825
71	1	2	1.59	1.91	5.99	5.01	0.5472
72	1	1	1.81	1.67	4.92	4.55	0.9913

Table 19. Evans Tillage Statistics

1	No Compaction
2	Wheel Traffic
3	Plow Pan

Plot	Till Treat	Wat Zone	BD_Shal	BD_Deep	EC_Shal	EC_Deep	Refl_2151.9
1	3	6	1.62	1.67	92.55	41.07	1.1406
2	3	5	1.59	1.94	64.69	57.15	0.4523
3	3	4	1.76	1.46	30.41	29.79	1.3730
4	3	3	1.54	1.64	52.58	39.96	1.0427
5	3	2	1.90	1.64	41.14	39.94	0.7041
6	3	1	1.80	1.77	41.30	40.65	1.0990
7	1	6	1.03	1.00	118.81	104.23	0.6213
8	1	5	0.86	1.50	88.15	95.25	0.8381
9	1	4	0.94	1.39	87.76	81.31	0.9957
10	1	3	1.32	1.27	58.02	68.52	0.9436
11	1	2	1.70	1.38	57.96	61.91	0.6833
12	1	1	1.51	1.33	45.38	61.26	0.6509
13	2	6	1.73	0.97	95.94	96.28	0.9665
14	2	5	1.52	1.36	110.94	72.51	0.8757
15	2	4	1.61	1.35	75.75	72.21	1.0677
16	2	3	1.71	1.66	13.63	11.35	1.2440
17	2	2	1.83	1.35	57.03	66.24	0.7227
18	2	1	1.72	1.68	53.15	63.12	0.3965
19	1	6	0.89	1.10	113.68	102.56	0.9664
20	1	5	1.34	1.53	18.53	20.41	1.1389
21	1	4	1.28	1.35	86.41	79.59	0.8865
22	1	3	1.67	1.51	56.12	68.08	1.2040
23	1	2	1.64	1.73	56.02	67.92	0.7531
24	1	1	1.86	1.74	56.11	68.51	0.7471
25	2	6	1.34	1.02	115.04	102.87	1.1613
26	2	5	1.60	1.44	24.53	43.30	1.1621
27	2	4	1.66	1.15	83.88	79.76	1.2985
28	2	3	1.85	1.50	65.30	74.82	0.8888
29	2	2	1.77	1.78	53.45	72.36	0.8730
30	2	1	1.79	1.56	55.51	68.97	0.8020
31	3	6	1.81	0.84	96.63	95.92	0.7759
32	3	5	1.68	1.72	95.86	86.14	0.9697
33	3	4	1.62	1.46	63.62	65.48	1.2024
34	3	3	1.71	1.79	64.50	71.46	1.3735
35	3	2	1.83	0.95	43.40	52.03	0.6143
36	3	1	1.78	1.66	43.38	63.39	0.6777
37	2	6	1.59	0.95	99.98	74.27	0.8202
38	2	5	1.72	1.64	64.18	22.86	1.0326
39	2	4	1.46	0.83	70.95	73.62	1.1264
40	2	3	1.47	1.61	52.96	51.44	1.1193
41	2	2	1.71	1.76	53.87	52.03	1.0095
42	2	1	1.68	1.71	47.75	47.23	0.4938
43	1	6	0.96	1.26	111.73	93.12	1.1218
44	1	5	0.97	1.45	62.68	32.25	1.0259
45	1	4	1.17	1.37	76.48	81.38	1.1933
46	1	3	1.57	1.17	52.96	67.24	0.9623
47	1	2	1.49	1.48	56.46	63.83	1.0023

Evans Statistics

1	No Compaction	62
2	Wheel Traffic	
3	Plow Pan	

Plot	Till Treat	Wat Zone	BD_Shal	BD_Deep	EC_Shal	EC_Deep	Refl_2151.9
48	1	1	1.46	1.61	57.72	64.87	0.8150
49	3	6	1.17	0.99	106.63	89.03	1.2112
50	3	5	1.05	0.95	26.80	23.54	1.0256
51	3	4	1.64	0.69	61.22	72.22	0.9825
52	3	3	1.54	0.75	53.43	64.53	1.0201
53	3	2	1.69	0.84	45.90	64.76	0.9828
54	3	1	1.62	1.17	53.01	72.30	0.8181
55	3	6	1.43	1.82	77.57	66.78	0.9886
56	3	5	1.27	1.56	47.99	40.86	1.1915
57	3	4	1.43	1.57	53.82	66.72	0.7876
58	3	3	1.60	1.66	48.28	61.54	0.6850
59	3	2	1.71	1.43	43.07	65.46	0.7593
60	3	1	1.67	0.82	43.39	69.13	0.8223
61	2	6	1.74	0.97	72.18	61.81	1.1028
62	2	5	1.86	1.74	15.26	19.96	1.1933
63	2	4	1.59	0.69	40.04	35.58	0.9672
64	2	3	1.78	0.72	30.16	30.48	0.8158
65	2	2	1.82	1.53	46.33	51.94	0.8157
66	2	1	1.67	0.84	31.52	58.18	0.8266
67	1	6	0.62	1.47	66.41	65.15	0.9802
68	1	5	1.28	1.11	4.74	4.91	1.2932
69	1	4	1.04	1.41	56.47	64.86	1.3473
70	1	3	1.37	1.37	51.08	66.31	0.8682
71	1	2	1.29	1.44	49.78	70.72	1.3267
72	1	1	1.21	0.82	49.53	74.48	1.2693

Table 20. Kaysville Tillage Statistics

1	No Compaction
2	Wheel Traffic
3	Plow Pan

Plot	Till Treat	Wat Zone	BD_Shal	BD_Deep	EC_Shal	EC_Deep	Refl_2151.9
1	3	6	2.13	1.81	26.81	19.45	0.7901
2	3	5	2.10	1.86	24.11	20.12	0.8433
3	3	4	2.07	1.88	28.65	20.42	0.4078
4	3	3	2.02	2.00	19.98	19.10	0.6031
5	3	2	1.74	1.94	20.69	15.08	0.5801
6	3	1	1.77	1.72	15.02	14.89	0.4781
7	1	6	1.87	1.66	30.00	21.98	0.7220
8	1	5	1.99	1.73	17.04	15.24	0.8639
9	1	4	1.91	1.79	16.06	14.48	0.6724
10	1	3	1.79	1.94	29.26	16.17	0.6186
11	1	2	1.91	1.92	15.34	14.54	0.8603
12	1	1	1.53	1.75	15.72	14.90	0.6483
13	2	6	1.87	2.06	32.34	23.14	0.9199
14	2	5	1.95	1.99	29.14	19.68	0.7131
15	2	4	1.98	1.79	21.02	20.94	0.6172
16	2	3	1.86	1.57	23.86	14.68	0.6723
17	2	2	1.81	1.70	25.16	26.06	0.6490
18	2	1	2.05	1.93	25.10	20.27	0.5384
19	1	6	1.61	1.74	32.37	23.40	0.8862
20	1	5	2.03	1.35	16.77	14.69	1.0645
21	1	4	1.62	1.75	11.01	10.44	0.8296
22	1	3	1.60	1.96	21.70	17.84	0.3900
23	1	2	1.81	1.75	17.30	16.99	0.7115
24	1	1	1.69	1.66	16.72	16.32	0.5393
25	2	6	1.84	1.04	31.33	24.25	0.7782
26	2	5	1.96	1.78	28.91	23.24	0.8559
27	2	4	1.98	1.52	29.92	21.53	0.8594
28	2	3	1.88	1.62	29.29	12.73	0.6191
29	2	2	1.91	1.79	22.33	20.62	0.7531
30	2	1	1.94	1.86	28.70	19.44	0.5089
31	3	6	2.08	1.85	30.69	22.04	0.7795
32	3	5	1.95	1.99	26.48	21.06	0.7438
33	3	4	2.06	1.94	21.38	17.94	0.8404
34	3	3	2.04	1.95	26.46	15.86	0.7965
35	3	2	2.03	1.87	15.90	22.23	0.7422
36	3	1	1.94	1.91	16.85	19.57	0.7836
37	2	6	2.13	1.90	33.75	22.69	0.9317
38	2	5	1.90	1.95	26.60	20.61	0.8036
39	2	4	1.79	1.93	25.24	18.90	0.7823
40	2	3	1.91	1.88	16.35	15.62	0.4202
41	2	2	1.97	1.79	15.93	18.14	0.7480
42	2	1	1.83	1.87	16.44	27.37	0.7516
43	1	6	1.64	2.07	31.30	23.62	0.9365
44	1	5	1.78	1.67	27.16	21.94	0.9035
45	1	4	1.92	1.86	14.42	11.86	0.8044
46	1	3	1.78	1.64	12.63	12.33	0.3307
47	1	2	1.83	1.83	14.16	16.91	0.6477

Kaysville Statistics

1	No Compaction	64
2	Wheel Traffic	
3	Plow Pan	

Plot	Till Treat	Wat Zone	BD_Shal	BD_Deep	EC_Shal	EC_Deep	Refl_2151.9
48	1	1	1.95	2.02	18.74	21.17	0.6270
49	3	6	1.82	1.44	32.02	23.91	0.9159
50	3	5	1.88	1.78	28.28	22.72	0.8768
51	3	4	2.03	1.81	19.97	19.87	0.7429
52	3	3	2.00	1.88	15.65	21.74	0.5877
53	3	2	2.11	1.82	22.41	22.89	0.8457
54	3	1	2.02	1.87	18.37	20.59	0.7653
55	3	6	1.98	2.01	30.88	25.16	0.8473
56	3	5	1.80	2.03	27.80	22.59	0.8381
57	3	4	2.03	1.70	17.68	22.09	0.5769
58	3	3	1.82	1.90	14.37	12.92	0.6750
59	3	2	1.84	1.80	22.23	21.39	0.8139
60	3	1	1.99	1.82	17.96	24.14	0.7845
61	2	6	1.98	2.06	32.57	25.13	0.7711
62	2	5	1.76	1.89	30.31	23.81	0.5513
63	2	4	2.01	1.79	20.92	21.32	0.6872
64	2	3	1.76	1.83	19.27	12.34	0.5329
65	2	2	1.81	1.84	27.05	16.72	0.7312
66	2	1	1.92	1.60	19.11	29.63	0.4801
67	1	6	2.02	1.60	21.01	18.14	0.9351
68	1	5	1.59	1.62	22.79	19.86	0.8588
69	1	4	1.45	1.80	13.94	13.98	0.2888
70	1	3	1.76	1.69	12.09	10.96	0.6352
71	1	2	1.98	1.93	12.75	15.42	0.7889
72	1	1	1.91	1.92	18.75	17.63	0.9467

Table 21. Probability Values for Treatments at the Greenville, Evans and Kaysville Research Farms
Greenville Soil: Millville, coarse-silty, carbonatic, mesic Typic Haploxerolls

	Bulk Density Shallow			Bulk Density Deep		
EC by Water Zone	1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow						
1 (dry)	0.84	0.32	0.31	0.21	0.30	0.64
2	0.93	0.73	0.92	0.73	0.35	0.50
3	0.59	0.52	0.98	0.58	0.51	0.32
4	0.83	0.58	0.78	0.94	0.37	0.03*
5	0.67	0.92	0.75	0.76	0.21	0.80
6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A
EC Deep						
1 (dry)	0.58	0.39	0.46	0.17	0.37	0.80
2	0.25	0.72	0.88	0.54	0.32	0.68
3	0.21	0.39	0.82	0.15	0.58	0.11
4	0.82	0.53	0.59	0.62	0.56	0.28
5	0.73	0.79	0.78	0.72	0.04*	0.57
6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A
NIR Reflectance						
1 (dry)	0.40	0.14	0.38	0.10*	0.14	0.69
2	0.88	0.07*	0.75	0.97	0.23	0.04*
3	0.99	0.89	0.16	0.99	0.58	0.59
4	0.79	0.64	0.13	0.51	0.23	0.87
5	0.40	0.72	0.11	0.98	0.15	0.31
6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A

Probability values at the Greenville Research Farm. The probability threshold is set at $\alpha = 0.10$, d.f. = 3. Only 5 of the 108 combinations had significant results.

Evans Soil: Nebeker, fine, montmorillonitic, mesic Pachic Argixerolls

	Bulk Density Shallow			Bulk Density Deep		
EC by Water Zone	1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow						
1 (dry)	0.90	0.37	0.31	0.51	0.14	0.22
2	0.26	0.97	0.58	0.91	0.16	0.48
3	0.62	0.09*	0.09*	0.98	0.41	0.34
4	0.59	0.63	0.01*	0.51	0.19	0.89
5	0.17	0.69	0.28	0.65	0.75	0.64
6 (wet)	0.11	0.52	0.50	0.16	0.53	0.02*
EC Deep						
1 (dry)	0.20	0.61	0.52	0.03*	0.51	0.42
2	0.68	0.59	0.05*	0.88	0.72	0.71
3	0.69	0.12	0.71	0.96	0.29	0.58
4	0.85	0.63	0.22	0.14	0.33	0.75
5	0.03*	0.04*	0.28	0.82	0.11	0.66
6 (wet)	0.30	0.75	0.52	0.00*	0.75	0.38
NIR Reflectance						
1 (dry)	0.17	0.32	0.87	0.26	0.36	0.86
2	0.03*	0.31	0.28	0.67	0.49	0.85
3	0.05*	0.63	0.02*	0.32	0.01*	0.60
4	0.26	0.11	0.41	0.65	0.18	0.27
5	0.25	0.69	0.85	0.63	0.74	0.02*
6 (wet)	0.67	0.30	0.59	0.10*	0.32	0.37

Probability values at the Evans Research Farm. The probability threshold is set at α = 0.10, d.f. = 3. 15 of the 108 combinations had significant results.

Kaysville Soil: Kidman, coarse-loamy, superactive, mesic Calcic Haploxerolls

	Bulk Density Shallow			**Bulk Density Deep**		
EC by Water Zone	1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow						
1 (dry)	0.10*	0.65	0.08*	0.52	0.92	0.19
2	0.67	0.16	0.90	0.58	0.50	0.36
3	0.61	0.60	0.12	0.45	0.30	0.61
4	0.33	0.73	0.40	0.54	0.01*	0.71
5	0.21	0.17	0.23	0.58	0.97	0.18
6 (wet)	0.14	0.33	0.49	0.26	0.08*	0.65
EC Deep						
1 (dry)	0.43	0.78	0.47	0.09*	0.67	0.28
2	0.31	0.92	0.29	0.41	0.28	0.09*
3	0.29	0.67	0.04*	0.03*	0.19	0.63
4	0.58	0.21	0.00*	0.21	0.13	0.44
5	0.15	0.68	0.34	0.47	0.31	0.05*
6 (wet)	0.01*	0.63	0.05*	0.19	0.75	0.33
NIR Reflectance						
1 (dry)	0.87	0.16	0.01*	0.49	0.83	0.16
2	0.58	0.71	0.62	0.47	0.03*	0.16
3	0.87	0.07*	0.46	0.24	0.26	0.21
4	0.22	0.86	0.22	0.56	0.27	0.93
5	0.78	0.45	0.86	0.24	0.72	0.66
6 (wet)	0.49	0.80	0.19	0.85	0.70	0.10*

Probability values at the Kaysville Research Farm. The probability threshold is set at $\alpha = 0.10$, d.f. =3. 14 of the 108 combinations had significant results.

Table 22. Measured Soil Characteristics at the Greenville Research Farm

Mass for BD and GWC

Farm: **Greenville**

Jay Payne

Radius 2.40 cm
Height 10.30 cm
Volume 186.38 cm^3

WET			WET			DRY			DRY											
#	Depth	Total	#	Depth	Total	#	Depth	Total	#	Depth	Total		GWC	δ_B		GWC	δ_B		EC Sh	EC Dp
1	A	374.6	1	B	340.8	1	A	340.9	1	B	312.1	1 A	0.09	1.83	1 B	0.08	1.67	1	5.2731	4.0129
2	A	350.3	2	B	345.9	2	A	327.1	2	B	317.4	2 A	0.07	1.75	2 B	0.08	1.70	2	5.9258	4.3752
3	A	355.7	3	B	363.5	3	A	325.7	3	B	331.6	3 A	0.08	1.75	3 B	0.09	1.78	3	6.1330	4.7995
4	A	349.3	4	B	384.4	4	A	320.3	4	B	351.0	4 A	0.08	1.72	4 B	0.09	1.88	4	6.6314	5.7793
5	A	365.1	5	B	362.9	5	A	332.1	5	B	330.9	5 A	0.09	1.78	5 B	0.09	1.78	5	6.9323	5.5295
6	A	346.4	6	B	333.4	6	A	316.8	6	B	306.2	6 A	0.09	1.70	6 B	0.08	1.64	6	8.0167	5.9770
7	A	354.2	7	B	335.6	7	A	328.6	7	B	304.0	7 A	0.07	1.76	7 B	0.09	1.63	7	5.5085	4.4690
8	A	357.0	8	B	362.1	8	A	326.8	8	B	331.4	8 A	0.08	1.75	8 B	0.08	1.78	8	5.5532	5.2797
9	A	363.9	9	B	385.3	9	A	330.8	9	B	352.0	9 A	0.09	1.77	9 B	0.09	1.89	9	6.5946	5.2728
10	A	351.6	10	B	384.7	10	A	317.1	10	B	351.1	10 A	0.10	1.70	10 B	0.09	1.88	10	7.2495	6.0525
11	A	371.7	11	B	367.0	11	A	335.2	11	B	333.8	11 A	0.10	1.80	11 B	0.09	1.79	11	7.8822	5.7603
12	A	360.0	12	B	378.8	12	A	325.5	12	B	345.4	12 A	0.10	1.75	12 B	0.09	1.85	12	8.3007	6.2733
13	A	381.2	13	B	369.4	13	A	356.6	13	B	337.2	13 A	0.06	1.91	13 B	0.09	1.81	13	-1.0000	-1.0000
14	A	343.9	14	B	337.5	14	A	316.1	14	B	313.9	14 A	0.08	1.70	14 B	0.07	1.68	14	8.5016	6.3346
15	A	368.4	15	B	354.7	15	A	338.0	15	B	328.1	15 A	0.08	1.81	15 B	0.07	1.76	15	7.0553	5.1781
16	A	370.8	16	B	375.0	16	A	340.1	16	B	344.6	16 A	0.08	1.82	16 B	0.08	1.85	16	9.1236	7.2939
17	A	374.3	17	B	378.0	17	A	345.8	17	B	348.2	17 A	0.08	1.86	17 B	0.08	1.87	17	9.9590	8.0740
18	A	357.3	18	B	321.7	18	A	330.7	18	B	294.8	18 A	0.07	1.77	18 B	0.08	1.58	18	7.9227	7.2789
19	A	356.8	19	B	347.0	19	A	319.2	19	B	311.7	19 A	0.11	1.71	19 B	0.10	1.67	19	-1.0000	-1.0000
20	A	301.4	20	B	361.3	20	A	270.2	20	B	328.2	20 A	0.10	1.45	20 B	0.09	1.76	20	5.2099	4.3078
21	A	284.8	21	B	363.2	21	A	262.8	21	B	329.8	21 A	0.08	1.41	21 B	0.09	1.77	21	6.6151	5.5219
22	A	312.4	22	B	346.0	22	A	289.9	22	B	312.8	22 A	0.07	1.56	22 B	0.10	1.68	22	5.8954	5.4573
23	A	291.0	23	B	286.3	23	A	271.3	23	B	261.8	23 A	0.07	1.46	23 B	0.09	1.40	23	5.8211	5.5179
24	A	363.0	24	B	373.9	24	A	333.7	24	B	338.6	24 A	0.08	1.79	24 B	0.09	1.82	24	7.3125	6.0566
25	A	373.7	25	B	375.3	25	A	349.0	25	B	345.1	25 A	0.07	1.87	25 B	0.08	1.85	25	4.7599	4.6161
26	A	367.4	26	B	356.8	26	A	341.4	26	B	329.0	26 A	0.07	1.83	26 B	0.08	1.77	26	6.4553	4.7318
27	A	373.3	27	B	355.4	27	A	342.7	27	B	326.4	27 A	0.08	1.84	27 B	0.08	1.75	27	6.4060	5.2503
28	A	373.8	28	B	380.5	28	A	342.0	28	B	347.8	28 A	0.09	1.83	28 B	0.09	1.87	28	8.2396	6.0684

Mass for BD and GWC

Farm: **Greenville**

Jay Payne

Radius	2.40	cm
Height	10.30	cm
Volume	186.38	cm^3

WET			WET		
#	Depth	Total	#	Depth	Total
29	A	382.9	29	B	329.3
30	A	394.8	30	B	343.0
31	A	355.6	31	B	396.1
32	A	364.2	32	B	392.5
33	A	360.8	33	B	364.0
34	A	356.3	34	B	344.2
35	A	361.7	35	B	374.5
36	A	362.1	36	B	364.1
37	A	358.0	37	B	361.4
38	A	331.2	38	B	401.3
39	A	325.1	39	B	311.3
40	A	346.0	40	B	392.0
41	A	357.1	41	B	350.4
42	A	313.7	42	B	387.1
43	A	365.3	43	B	356.3
44	A	375.7	44	B	358.5
45	A	376.1	45	B	335.9
46	A	379.0	46	B	350.8
47	A	377.7	47	B	328.1
48	A	354.8	48	B	381.3
49	A	362.3	49	B	344.6
50	A	374.9	50	B	383.5
51	A	374.7	51	B	372.6
52	A	363.7	52	B	345.4
53	A	351.8	53	B	362.6
54	A	363.7	54	B	282.5
55	A	346.3	55	B	388.8
56	A	357.6	56	B	400.6

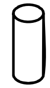
DRY			DRY		
#	Depth	Total	#	Depth	Total
29	A	349.6	29	B	302.6
30	A	360.3	30	B	314.6
31	A	323.6	31	B	360.9
32	A	325.6	32	B	353.3
33	A	326.4	33	B	331.4
34	A	326.2	34	B	313.1
35	A	330.4	35	B	334.8
36	A	333.1	36	B	333.0
37	A	329.4	37	B	329.0
38	A	305.2	38	B	366.1
39	A	300.7	39	B	286.5
40	A	318.2	40	B	357.3
41	A	320.6	41	B	318.9
42	A	283.1	42	B	349.8
43	A	342.6	43	B	327.9
44	A	351.0	44	B	329.7
45	A	347.6	45	B	313.6
46	A	348.9	46	B	322.2
47	A	346.7	47	B	300.6
48	A	325.0	48	B	346.0
49	A	326.1	49	B	309.7
50	A	336.8	50	B	341.0
51	A	339.1	51	B	336.5
52	A	330.0	52	B	313.3
53	A	322.4	53	B	331.6
54	A	336.1	54	B	262.6
55	A	321.4	55	B	361.3
56	A	336.9	56	B	389.4

	GWC	δ_B		GWC	δ_B		EC Sh	EC Dp
29 A	0.09	1.88	29 B	0.08	1.62	29	7.8572	6.3067
30 A	0.09	1.93	30 B	0.08	1.69	30	7.9500	6.2735
31 A	0.09	1.74	31 B	0.09	1.94	31	-1.0000	-1.0000
32 A	0.11	1.75	32 B	0.10	1.90	32	8.0733	6.4119
33 A	0.10	1.75	33 B	0.09	1.78	33	7.4639	5.8385
34 A	0.08	1.75	34 B	0.09	1.68	34	6.9879	6.3849
35 A	0.09	1.77	35 B	0.11	1.80	35	7.7748	6.6281
36 A	0.08	1.79	36 B	0.09	1.79	36	6.9654	6.9282
37 A	0.08	1.77	37 B	0.09	1.77	37	5.2427	4.4461
38 A	0.08	1.64	38 B	0.09	1.96	38	5.4104	4.5159
39 A	0.08	1.61	39 B	0.08	1.54	39	5.2667	4.4882
40 A	0.08	1.71	40 B	0.09	1.92	40	6.0029	4.8653
41 A	0.10	1.72	41 B	0.09	1.71	41	5.9072	4.6961
42 A	0.10	1.52	42 B	0.10	1.88	42	7.7712	6.2767
43 A	0.06	1.84	43 B	0.08	1.76	43	5.2009	4.0130
44 A	0.07	1.88	44 B	0.08	1.77	44	4.4295	3.0541
45 A	0.08	1.86	45 B	0.07	1.68	45	5.2176	3.7786
46 A	0.08	1.87	46 B	0.08	1.73	46	6.2043	4.8451
47 A	0.08	1.86	47 B	0.08	1.61	47	8.3731	6.3025
48 A	0.08	1.74	48 B	0.09	1.86	48	8.7166	6.6231
49 A	0.10	1.75	49 B	0.10	1.66	49	-1.0000	-1.0000
50 A	0.10	1.81	50 B	0.11	1.83	50	7.0270	6.3272
51 A	0.10	1.82	51 B	0.10	1.81	51	7.6705	6.2191
52 A	0.09	1.77	52 B	0.09	1.68	52	7.2599	6.2217
53 A	0.08	1.73	53 B	0.09	1.78	53	6.9795	6.5802
54 A	0.08	1.80	54 B	0.07	1.41	54	5.7701	5.4354
55 A	0.07	1.72	55 B	0.07	1.94	55	3.3341	2.8257
56 A	0.06	1.81	56 B	0.03	2.09	56	5.6541	5.3307

Mass for BD and GWC

Farm: **Greenville**

Jay Payne



Radius	2.40	cm
Height	10.30	cm
Volume	186.38	cm^3

WET		
#	**Depth**	**Total**
57	A	356.7
58	A	357.4
59	A	377.2
60	A	371.4
61	A	356.6
62	A	383.2
63	A	364.2
64	A	360.3
65	A	359.4
66	A	359.5
67	A	337.5
68	A	325.0
69	A	348.1
70	A	331.8
71	A	313.3
72	A	365.9

WET		
#	**Depth**	**Total**
57	B	345.3
58	B	355.5
59	B	360.4
60	B	353.0
61	B	322.9
62	B	364.4
63	B	382.2
64	B	344.9
65	B	374.1
66	B	333.8
67	B	353.7
68	B	376.7
69	B	364.7
70	B	309.8
71	B	385.1
72	B	338.8

DRY		
#	**Depth**	**Total**
57	A	328.0
58	A	323.3
59	A	340.2
60	A	331.4
61	A	323.6
62	A	349.8
63	A	333.8
64	A	332.9
65	A	334.1
66	A	336.4
67	A	311.9
68	A	300.0
69	A	322.3
70	A	306.6
71	A	296.7
72	A	337.1

DRY		
#	**Depth**	**Total**
57	B	323.3
58	B	319.1
59	B	325.5
60	B	315.1
61	B	296.0
62	B	331.6
63	B	348.0
64	B	317.6
65	B	344.1
66	B	309.7
67	B	318.9
68	B	342.2
69	B	333.9
70	B	284.4
71	B	355.5
72	B	310.4

	GWC	δ_B
57 A	0.08	1.76
58 A	0.10	1.73
59 A	0.10	1.83
60 A	0.11	1.78
61 A	0.09	1.74
62 A	0.09	1.88
63 A	0.08	1.79
64 A	0.08	1.79
65 A	0.07	1.79
66 A	0.06	1.80
67 A	0.08	1.67
68 A	0.08	1.61
69 A	0.07	1.73
70 A	0.08	1.64
71 A	0.05	1.59
72 A	0.08	1.81

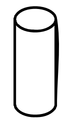
	GWC	δ_B
57 B	0.06	1.73
58 B	0.10	1.71
59 B	0.10	1.75
60 B	0.11	1.69
61 B	0.08	1.59
62 B	0.09	1.78
63 B	0.09	1.87
64 B	0.08	1.70
65 B	0.08	1.85
66 B	0.07	1.66
67 B	0.10	1.71
68 B	0.09	1.84
69 B	0.08	1.79
70 B	0.08	1.53
71 B	0.08	1.91
72 B	0.08	1.67

	EC Sh	EC Dp
57	6.4705	5.5205
58	6.4155	5.3697
59	7.5704	5.9314
60	8.9779	7.6896
61	-1.0000	-1.0000
62	10.1477	8.3741
63	9.5714	8.0797
64	7.3612	6.0933
65	10.1196	8.5934
66	7.6315	6.5158
67	-1.0000	-1.0000
68	7.0043	5.5849
69	6.0600	5.3678
70	5.7652	4.4991
71	5.9882	5.0100
72	4.9166	4.5533

Table 23. Measured Soil Characteristics at the Evans Research Farm

Mass for BD and GWC   Farm: Evans

Jay Payne

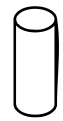


Radius 2.40 cm
Height 10.30 cm
Volume 186.38 cm^3

WET			WET			DRY			DRY											
#	Depth	Total	#	Depth	Total	#	Depth	Total	#	Depth	Total	#	GWC	δ_B	#	GWC	δ_B	#	EC Sh	EC Dp
1	A	356.8	1	B	375.1	1	A	302.4	1	B	311.0	1 A	0.16	1.62	1 B	0.17	1.67	1	92.5508	41.0673
2	A	348.4	2	B	428.7	2	A	296.0	2	B	361.0	2 A	0.15	1.59	2 B	0.16	1.94	2	64.6920	57.1500
3	A	385.5	3	B	315.3	3	A	328.9	3	B	272.5	3 A	0.15	1.76	3 B	0.14	1.46	3	30.4120	29.7875
4	A	326.0	4	B	356.1	4	A	286.8	4	B	306.0	4 A	0.12	1.54	4 B	0.14	1.64	4	52.5799	39.9614
5	A	401.6	5	B	354.3	5	A	354.1	5	B	306.6	5 A	0.12	1.90	5 B	0.13	1.64	5	41.1352	39.9389
6	A	374.7	6	B	379.9	6	A	335.2	6	B	329.6	6 A	0.11	1.80	6 B	0.13	1.77	6	41.2981	40.6481
7	A	224.4	7	B	213.8	7	A	191.1	7	B	185.9	7 A	0.15	1.03	7 B	0.13	1.00	7	118.8100	104.2267
8	A	183.5	8	B	324.9	8	A	160.0	8	B	280.3	8 A	0.13	0.86	8 B	0.14	1.50	8	88.1473	95.2500
9	A	202.0	9	B	298.1	9	A	175.4	9	B	258.5	9 A	0.13	0.94	9 B	0.13	1.39	9	87.7646	81.3078
10	A	272.0	10	B	260.2	10	A	245.6	10	B	235.8	10 A	0.10	1.32	10 B	0.09	1.27	10	58.0156	68.5238
11	A	361.6	11	B	290.5	11	A	316.6	11	B	257.7	11 A	0.12	1.70	11 B	0.11	1.38	11	57.9639	61.9078
12	A	317.5	12	B	262.7	12	A	281.9	12	B	248.3	12 A	0.11	1.51	12 B	0.05	1.33	12	45.3794	61.2604
13	A	383.4	13	B	212.1	13	A	322.4	13	B	180.4	13 A	0.16	1.73	13 B	0.15	0.97	13	95.9434	96.2805
14	A	335.6	14	B	303.2	14	A	284.2	14	B	252.7	14 A	0.15	1.52	14 B	0.17	1.36	14	110.9438	72.5149
15	A	348.7	15	B	301.4	15	A	300.2	15	B	252.1	15 A	0.14	1.61	15 B	0.16	1.35	15	75.7480	72.2059
16	A	356.7	16	B	369.3	16	A	318.0	16	B	310.3	16 A	0.11	1.71	16 B	0.16	1.66	16	13.6250	11.3484
17	A	376.9	17	B	290.9	17	A	340.3	17	B	251.3	17 A	0.10	1.83	17 B	0.14	1.35	17	57.0330	66.2440
18	A	357.3	18	B	357.4	18	A	321.2	18	B	312.3	18 A	0.10	1.72	18 B	0.13	1.68	18	53.1498	63.1162
19	A	191.8	19	B	245.8	19	A	166.5	19	B	205.9	19 A	0.13	0.89	19 B	0.16	1.10	19	113.6834	102.5619
20	A	290.2	20	B	340.4	20	A	249.7	20	B	284.5	20 A	0.14	1.34	20 B	0.16	1.53	20	18.5300	20.4107
21	A	266.9	21	B	292.6	21	A	239.2	21	B	251.8	21 A	0.10	1.28	21 B	0.14	1.35	21	86.4077	79.5908
22	A	356.3	22	B	311.7	22	A	311.9	22	B	280.8	22 A	0.12	1.67	22 B	0.10	1.51	22	56.1218	68.0794
23	A	345.9	23	B	374.8	23	A	305.8	23	B	322.7	23 A	0.12	1.64	23 B	0.14	1.73	23	56.0175	67.9185
24	A	393.1	24	B	384.1	24	A	345.9	24	B	324.4	24 A	0.12	1.86	24 B	0.16	1.74	24	56.1081	68.5099
25	A	294.8	25	B	224.4	25	A	250.4	25	B	190.3	25 A	0.15	1.34	25 B	0.15	1.02	25	115.0371	102.8706
26	A	354.9	26	B	323.8	26	A	299.1	26	B	269.2	26 A	0.16	1.60	26 B	0.17	1.44	26	24.5250	43.3021
27	A	364.1	27	B	243.2	27	A	310.3	27	B	213.9	27 A	0.15	1.66	27 B	0.12	1.15	27	83.8813	79.7591
28	A	390.1	28	B	325.2	28	A	344.0	28	B	280.0	28 A	0.12	1.85	28 B	0.14	1.50	28	65.3009	74.8187

Mass for BD and GWC   Farm: Evans

Jay Payne



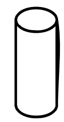
Radius 2.40 cm
Height 10.30 cm
Volume 186.38 cm^3

WET			WET			DRY			DRY		
#	Depth	Total	#	Depth	Total	#	Depth	Total	#	Depth	Total
29	A	371.5	29	B	390.6	29	A	329.4	29	B	331.1
30	A	374.3	30	B	336.4	30	A	333.3	30	B	291.1
31	A	407.8	31	B	190.4	31	A	338.2	31	B	156.6
32	A	374.4	32	B	387.6	32	A	314.0	32	B	320.5
33	A	357.5	33	B	318.2	33	A	302.6	33	B	272.6
34	A	369.8	34	B	397.4	34	A	318.2	34	B	333.1
35	A	395.6	35	B	210.0	35	A	342.0	35	B	177.1
36	A	376.6	36	B	363.3	36	A	332.1	36	B	309.9
37	A	352.9	37	B	217.2	37	A	295.6	37	B	177.2
38	A	383.1	38	B	372.0	38	A	320.3	38	B	306.0
39	A	317.0	39	B	179.9	39	A	271.7	39	B	154.1
40	A	315.3	40	B	354.7	40	A	273.2	40	B	300.5
41	A	360.0	41	B	384.8	41	A	318.3	41	B	327.9
42	A	350.7	42	B	371.1	42	A	314.0	42	B	318.2
43	A	211.1	43	B	278.7	43	A	179.4	43	B	234.1
44	A	211.3	44	B	322.4	44	A	180.3	44	B	269.8
45	A	253.9	45	B	269.1	45	A	217.3	45	B	254.8
46	A	324.5	46	B	245.1	46	A	292.2	46	B	218.8
47	A	294.3	47	B	306.9	47	A	277.4	47	B	275.5
48	A	290.0	48	B	336.7	48	A	273.0	48	B	299.7
49	A	258.0	49	B	223.9	49	A	217.8	49	B	185.2
50	A	230.8	50	B	213.1	50	A	196.4	50	B	177.0
51	A	356.1	51	B	194.5	51	A	306.4	51	B	128.8
52	A	330.3	52	B	161.3	52	A	287.5	52	B	138.9
53	A	351.0	53	B	182.3	53	A	314.4	53	B	157.4
54	A	334.9	54	B	249.5	54	A	302.3	54	B	218.0
55	A	321.3	55	B	405.9	55	A	267.0	55	B	338.8
56	A	279.7	56	B	346.7	56	A	236.1	56	B	290.9

#	GWC	δ_B	#	GWC	δ_B	#	EC Sh	EC Dp
29 A	0.11	1.77	29 B	0.15	1.78	29	53.4481	72.3608
30 A	0.11	1.79	30 B	0.13	1.56	30	55.5118	68.9739
31 A	0.17	1.81	31 B	0.18	0.84	31	96.6294	95.9201
32 A	0.16	1.68	32 B	0.17	1.72	32	95.8558	86.1421
33 A	0.15	1.62	33 B	0.14	1.46	33	63.6163	65.4759
34 A	0.14	1.71	34 B	0.16	1.79	34	64.4960	71.4609
35 A	0.14	1.83	35 B	0.16	0.95	35	43.3952	52.0269
36 A	0.12	1.78	36 B	0.15	1.66	36	43.3772	63.3852
37 A	0.16	1.59	37 B	0.18	0.95	37	99.9839	74.2672
38 A	0.16	1.72	38 B	0.18	1.64	38	64.1818	22.8600
39 A	0.14	1.46	39 B	0.14	0.83	39	70.9524	73.6174
40 A	0.13	1.47	40 B	0.15	1.61	40	52.9645	51.4350
41 A	0.12	1.71	41 B	0.15	1.76	41	53.8656	52.0328
42 A	0.10	1.68	42 B	0.14	1.71	42	47.7549	47.2339
43 A	0.15	0.96	43 B	0.16	1.26	43	111.7319	93.1174
44 A	0.15	0.97	44 B	0.16	1.45	44	62.6750	32.2489
45 A	0.14	1.17	45 B	0.05	1.37	45	76.4839	81.3840
46 A	0.10	1.57	46 B	0.11	1.17	46	52.9583	67.2428
47 A	0.06	1.49	47 B	0.10	1.48	47	56.4596	63.8299
48 A	0.06	1.46	48 B	0.11	1.61	48	57.7205	64.8653
49 A	0.16	1.17	49 B	0.17	0.99	49	106.6255	89.0317
50 A	0.15	1.05	50 B	0.17	0.95	50	26.7958	23.5368
51 A	0.14	1.64	51 B	0.34	0.69	51	61.2213	72.2180
52 A	0.13	1.54	52 B	0.14	0.75	52	53.4262	64.5325
53 A	0.10	1.69	53 B	0.14	0.84	53	45.9036	64.7614
54 A	0.10	1.62	54 B	0.13	1.17	54	53.0136	72.2962
55 A	0.17	1.43	55 B	0.17	1.82	55	77.5743	66.7801
56 A	0.16	1.27	56 B	0.16	1.56	56	47.9870	40.8567

Mass for BD and GWC Farm: Evans

Jay Payne



Radius 2.40 cm
Height 10.30 cm
Volume 186.38 cm^3

WET		
#	Depth	Total
57	A	303.9
58	A	341.9
59	A	360.3
60	A	348.7
61	A	385.1
62	A	400.5
63	A	332.2
64	A	380.2
65	A	380.4
66	A	340.2
67	A	134.0
68	A	265.7
69	A	220.7
70	A	282.2
71	A	263.9
72	A	278.9

WET		
#	Depth	Total
57	B	344.5
58	B	359.1
59	B	309.1
60	B	177.9
61	B	212.3
62	B	376.0
63	B	148.8
64	B	152.1
65	B	328.1
66	B	179.6
67	B	315.6
68	B	232.3
69	B	294.0
70	B	280.4
71	B	308.4
72	B	175.3

DRY		
#	Depth	Total
57	A	267.4
58	A	297.9
59	A	319.2
60	A	311.1
61	A	324.3
62	A	347.1
63	A	295.9
64	A	332.0
65	A	340.1
66	A	311.4
67	A	114.9
68	A	239.5
69	A	194.1
70	A	254.7
71	A	239.8
72	A	225.3

DRY		
#	Depth	Total
57	B	292.2
58	B	309.2
59	B	267.3
60	B	153.3
61	B	180.7
62	B	323.5
63	B	128.8
64	B	133.8
65	B	284.8
66	B	156.9
67	B	273.6
68	B	207.6
69	B	263.2
70	B	255.5
71	B	268.3
72	B	152.0

#	GWC	δ_B
57 A	0.12	1.43
58 A	0.13	1.60
59 A	0.11	1.71
60 A	0.11	1.67
61 A	0.16	1.74
62 A	0.13	1.86
63 A	0.11	1.59
64 A	0.13	1.78
65 A	0.11	1.82
66 A	0.08	1.67
67 A	0.14	0.62
68 A	0.10	1.28
69 A	0.12	1.04
70 A	0.10	1.37
71 A	0.09	1.29
72 A	0.19	1.21

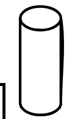
#	GWC	δ_B
57 B	0.15	1.57
58 B	0.14	1.66
59 B	0.14	1.43
60 B	0.14	0.82
61 B	0.15	0.97
62 B	0.14	1.74
63 B	0.13	0.69
64 B	0.12	0.72
65 B	0.13	1.53
66 B	0.13	0.84
67 B	0.13	1.47
68 B	0.11	1.11
69 B	0.10	1.41
70 B	0.09	1.37
71 B	0.13	1.44
72 B	0.13	0.82

#	EC Sh	EC Dp
57	53.8244	66.7158
58	48.2845	61.5403
59	43.0741	65.4561
60	43.3918	69.1320
61	72.1818	61.8110
62	15.2600	19.9571
63	40.0413	35.5788
64	30.1597	30.4800
65	46.3250	51.9376
66	31.5245	58.1758
67	66.4094	65.1480
68	4.7391	4.9129
69	56.4749	64.8576
70	51.0806	66.3076
71	49.7767	70.7177
72	49.5335	74.4818

Table 24. Measured Soil Characteristics at the Kaysville Research Farm

Mass for BD and GWC Farm: Kaysville

Jay Payne



Radius 2.4 cm
Height 10.3 cm
Volume 186.4 cm^3

WET			WET			DRY			DRY				GWC	δ_B		GWC	δ_B		EC Sh	EC Dp
#	Depth	Total	#	Depth	Total	#	Depth	Total	#	Depth	Total									
1	A	436.8	1	B	366.9	1	A	396.2	1	B	337.3	1 A	0.09	2.1	1 B	0.08	1.8	1	26.8118	19.4480
2	A	426.5	2	B	372.9	2	A	391.2	2	B	346.7	2 A	0.08	2.1	2 B	0.07	1.9	2	24.1130	20.1234
3	A	417.1	3	B	378.9	3	A	385.1	3	B	350.9	3 A	0.08	2.1	3 B	0.07	1.9	3	28.6531	20.4177
4	A	399.8	4	B	398.4	4	A	376.2	4	B	372	4 A	0.06	2.0	4 B	0.07	2.0	4	19.9804	19.0964
5	A	343.2	5	B	387.2	5	A	325.2	5	B	362.5	5 A	0.05	1.7	5 B	0.06	1.9	5	20.6879	15.0818
6	A	342.6	6	B	335.1	6	A	330.3	6	B	319.7	6 A	0.04	1.8	6 B	0.05	1.7	6	15.0230	14.8913
7	A	397.2	7	B	352.8	7	A	348.4	7	B	310.3	7 A	0.12	1.9	7 B	0.12	1.7	7	29.9975	21.9791
8	A	406.9	8	B	349.8	8	A	371.5	8	B	322.9	8 A	0.09	2.0	8 B	0.08	1.7	8	17.0360	15.2407
9	A	384.9	9	B	356.9	9	A	356.9	9	B	333.2	9 A	0.07	1.9	9 B	0.07	1.8	9	16.0606	14.4781
10	A	356.1	10	B	393.3	10	A	333.1	10	B	360.7	10 A	0.06	1.8	10 B	0.08	1.9	10	29.2649	16.1706
11	A	382.5	11	B	385.0	11	A	356	11	B	357.3	11 A	0.07	1.9	11 B	0.07	1.9	11	15.3416	14.5374
12	A	290.9	12	B	340.9	12	A	284.6	12	B	325.9	12 A	0.02	1.5	12 B	0.04	1.7	12	15.7221	14.9013
13	A	383.7	13	B	426.6	13	A	348.2	13	B	384.2	13 A	0.09	1.9	13 B	0.10	2.1	13	32.3379	23.1430
14	A	398.0	14	B	406.5	14	A	363.7	14	B	371.8	14 A	0.09	2.0	14 B	0.09	2.0	14	29.1424	19.6763
15	A	400.9	15	B	360.7	15	A	369.8	15	B	333.5	15 A	0.08	2.0	15 B	0.08	1.8	15	21.0152	20.9367
16	A	366.4	16	B	308.9	16	A	347.2	16	B	293.3	16 A	0.05	1.9	16 B	0.05	1.6	16	23.8631	14.6807
17	A	355.1	17	B	336.5	17	A	337.9	17	B	317.1	17 A	0.05	1.8	17 B	0.06	1.7	17	25.1560	26.0553
18	A	403.1	18	B	382.0	18	A	382.5	18	B	359.4	18 A	0.05	2.1	18 B	0.06	1.9	18	25.0982	20.2692
19	A	333.8	19	B	366.1	19	A	299.4	19	B	323.5	19 A	0.10	1.6	19 B	0.12	1.7	19	32.3668	23.3956
20	A	410.8	20	B	265.0	20	A	378.2	20	B	251.2	20 A	0.08	2.0	20 B	0.05	1.3	20	16.7682	14.6879
21	A	313.4	21	B	342.9	21	A	302.4	21	B	325.4	21 A	0.04	1.6	21 B	0.05	1.7	21	11.0091	10.4444
22	A	307.2	22	B	379.9	22	A	298	22	B	364.8	22 A	0.03	1.6	22 B	0.04	2.0	22	21.6978	17.8420
23	A	348.0	23	B	341.1	23	A	336.8	23	B	325.3	23 A	0.03	1.8	23 B	0.05	1.7	23	17.3031	16.9906
24	A	330.9	24	B	320.1	24	A	315.5	24	B	309.4	24 A	0.05	1.7	24 B	0.03	1.7	24	16.7247	16.3179
25	A	375.1	25	B	136.8	25	A	342.8	25	B	96.5	25 A	0.09	1.8	25 B	0.29	1.0	25	31.3317	24.2549
26	A	397.3	26	B	361.8	26	A	364.9	26	B	331.7	26 A	0.08	2.0	26 B	0.08	1.8	26	28.9058	23.2395
27	A	398.4	27	B	302.6	27	A	368.3	27	B	283.5	27 A	0.08	2.0	27 B	0.06	1.5	27	29.9177	21.5319
28	A	372.7	28	B	321.1	28	A	350.8	28	B	301.8	28 A	0.06	1.9	28 B	0.06	1.6	28	29.2938	12.7334

Mass for BD and GWC   Farm: Kaysville

Jay Payne

Radius 2.4 cm
Height 10.3 cm
Volume 186.4 cm^3

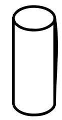
WET			WET			DRY			DRY		
#	Depth	Total	#	Depth	Total	#	Depth	Total	#	Depth	Total
29	A	377.0	29	B	354.6	29	A	356.7	29	B	334
30	A	382.5	30	B	371.1	30	A	361.2	30	B	347.5
31	A	427.2	31	B	378.8	31	A	388.4	31	B	344.4
32	A	397.1	32	B	403.8	32	A	363.9	32	B	371.7
33	A	413.8	33	B	390.2	33	A	383.8	33	B	362.2
34	A	406.9	34	B	390.5	34	A	379.4	34	B	362.8
35	A	400.9	35	B	373.8	35	A	378.3	35	B	348.8
36	A	385.4	36	B	380.2	36	A	361.4	36	B	356.5
37	A	437.5	37	B	392.3	37	A	396.1	37	B	353.3
38	A	385.6	38	B	396.4	38	A	354.6	38	B	363.5
39	A	359.7	39	B	387.3	39	A	334.5	39	B	359.5
40	A	379.4	40	B	376.0	40	A	356.7	40	B	351.1
41	A	391.5	41	B	355.7	41	A	368	41	B	333
42	A	358.6	42	B	371.3	42	A	340.5	42	B	349.1
43	A	345.1	43	B	436.9	43	A	306.4	43	B	385.5
44	A	365.8	44	B	344.8	44	A	331.8	44	B	311
45	A	386.5	45	B	380.0	45	A	357.2	45	B	347.3
46	A	343.5	46	B	323.2	46	A	331.4	46	B	305.3
47	A	355.8	47	B	371.2	47	A	341	47	B	341.7
48	A	390.1	48	B	409.0	48	A	363.8	48	B	376.3
49	A	374.3	49	B	294.9	49	A	338.6	49	B	268.1
50	A	384.8	50	B	366.7	50	A	349.9	50	B	332.1
51	A	408.9	51	B	364.2	51	A	378.4	51	B	336.8
52	A	392.9	52	B	373.1	52	A	372	52	B	350.8
53	A	424.5	53	B	362.9	53	A	392.7	53	B	339.1
54	A	400.0	54	B	379.5	54	A	376.9	54	B	349.4
55	A	405.0	55	B	410.5	55	A	368.4	55	B	374
56	A	366.2	56	B	414.0	56	A	335.1	56	B	378

	GWC	δ_B		GWC	δ_B		EC Sh	EC Dp
29 A	0.05	1.9	29 B	0.06	1.8	29	22.3301	20.6181
30 A	0.06	1.9	30 B	0.06	1.9	30	28.7030	19.4388
31 A	0.09	2.1	31 B	0.09	1.8	31	30.6870	22.0417
32 A	0.08	2.0	32 B	0.08	2.0	32	26.4816	21.0614
33 A	0.07	2.1	33 B	0.07	1.9	33	21.3756	17.9384
34 A	0.07	2.0	34 B	0.07	1.9	34	26.4574	15.8610
35 A	0.06	2.0	35 B	0.07	1.9	35	15.8952	22.2287
36 A	0.06	1.9	36 B	0.06	1.9	36	16.8462	19.5695
37 A	0.09	2.1	37 B	0.10	1.9	37	33.7539	22.6872
38 A	0.08	1.9	38 B	0.08	2.0	38	26.6001	20.6135
39 A	0.07	1.8	39 B	0.07	1.9	39	25.2383	18.9042
40 A	0.06	1.9	40 B	0.07	1.9	40	16.3500	15.6228
41 A	0.06	2.0	41 B	0.06	1.8	41	15.9336	18.1368
42 A	0.05	1.8	42 B	0.06	1.9	42	16.4364	27.3699
43 A	0.11	1.6	43 B	0.12	2.1	43	31.3000	23.6158
44 A	0.09	1.8	44 B	0.10	1.7	44	27.1583	21.9417
45 A	0.08	1.9	45 B	0.09	1.9	45	14.4195	11.8573
46 A	0.04	1.8	46 B	0.06	1.6	46	12.6280	12.3330
47 A	0.04	1.8	47 B	0.08	1.8	47	14.1588	16.9149
48 A	0.07	2.0	48 B	0.08	2.0	48	18.7372	21.1674
49 A	0.10	1.8	49 B	0.09	1.4	49	32.0209	23.9073
50 A	0.09	1.9	50 B	0.09	1.8	50	28.2799	22.7217
51 A	0.07	2.0	51 B	0.08	1.8	51	19.9743	19.8705
52 A	0.05	2.0	52 B	0.06	1.9	52	15.6537	21.7359
53 A	0.07	2.1	53 B	0.07	1.8	53	22.4093	22.8899
54 A	0.06	2.0	54 B	0.08	1.9	54	18.3734	20.5863
55 A	0.09	2.0	55 B	0.09	2.0	55	30.8847	25.1604
56 A	0.08	1.8	56 B	0.09	2.0	56	27.8047	22.5937

Mass for BD and GWC

Farm: **Kaysville**

Jay Payne



Radius 2.4 cm
Height 10.3 cm
Volume 186.4 cm^3

WET		
#	Depth	Total
57	A	403.2
58	A	359.9
59	A	364.9
60	A	398.0
61	A	404.4
62	A	358.3
63	A	400.7
64	A	344.7
65	A	355.9
66	A	378.6
67	A	414.4
68	A	317.6
69	A	290.3
70	A	339.9
71	A	384.8
72	A	371.3

WET		
#	Depth	Total
57	B	336.2
58	B	380.2
59	B	362.6
60	B	364.8
61	B	425.0
62	B	386.8
63	B	356.4
64	B	363.1
65	B	367.1
66	B	319.6
67	B	324.6
68	B	325.7
69	B	362.7
70	B	334.3
71	B	379.6
72	B	384.7

DRY		
#	Depth	Total
57	A	377.5
58	A	338.6
59	A	342.6
60	A	370.6
61	A	368.3
62	A	328.8
63	A	374.4
64	A	327.8
65	A	337.6
66	A	358.2
67	A	377.4
68	A	295.6
69	A	269.9
70	A	327.4
71	A	369.2
72	A	356.6

DRY		
#	Depth	Total
57	B	316.2
58	B	355
59	B	336.4
60	B	338.6
61	B	383.6
62	B	352.3
63	B	333.7
64	B	341.9
65	B	343.1
66	B	297.8
67	B	299
68	B	301.4
69	B	336.3
70	B	314.8
71	B	359.4
72	B	357.2

	GWC	δ_B
57 A	0.06	2.0
58 A	0.06	1.8
59 A	0.06	1.8
60 A	0.07	2.0
61 A	0.09	2.0
62 A	0.08	1.8
63 A	0.07	2.0
64 A	0.05	1.8
65 A	0.05	1.8
66 A	0.05	1.9
67 A	0.09	2.0
68 A	0.07	1.6
69 A	0.07	1.4
70 A	0.04	1.8
71 A	0.04	2.0
72 A	0.04	1.9

	GWC	δ_B
57 B	0.06	1.7
58 B	0.07	1.9
59 B	0.07	1.8
60 B	0.07	1.8
61 B	0.10	2.1
62 B	0.09	1.9
63 B	0.06	1.8
64 B	0.06	1.8
65 B	0.07	1.8
66 B	0.07	1.6
67 B	0.08	1.6
68 B	0.07	1.6
69 B	0.07	1.8
70 B	0.06	1.7
71 B	0.05	1.9
72 B	0.07	1.9

	EC Sh	EC Dp
57	17.6821	22.0929
58	14.3652	12.9205
59	22.2301	21.3874
60	17.9573	24.1380
61	32.5670	25.1293
62	30.3145	23.8144
63	20.9204	21.3216
64	19.2697	12.3429
65	27.0454	16.7241
66	19.1119	29.6274
67	21.0149	18.1422
68	22.7941	19.8563
69	13.9434	13.9832
70	12.0860	10.9603
71	12.7465	15.4160
72	18.7510	17.6282

Table 25. Treatment Means Squared Values

Soil: Millville, coarse-silty, carbonatic, mesic Typic Haploxerolls
Greenville

	Bulk Density Shallow			Bulk Density Deep		
EC by Water Zone	1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow						
1 (dry)	0.53	3.57	3.10	1.72	3.62	2.03
2	0.01	5.43	0.27	0.05	10.16	1.29
3	0.13	2.98	0.01	0.13	3.01	0.18
4	0.06	2.13	0.18	0.02	2.78	0.45
5	0.61	0.22	0.14	0.48	1.41	0.11
6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A
EC Deep						
1 (dry)	0.79	3.03	3.48	1.16	3.09	1.63
2	0.38	5.05	0.20	0.29	9.52	0.45
3	0.30	2.77	0.14	0.30	2.19	0.43
4	0.07	2.27	0.13	0.14	2.18	0.19
5	0.28	0.60	0.06	0.28	1.59	0.10
6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A
NIR Reflectance						
1 (dry)	0.06	0.04	0.06	0.07	0.04	0.04
2	0.01	0.01	0.02	0.00	0.01	0.05
3	0.00	0.00	0.03	0.00	0.01	0.02
4	0.02	0.01	0.03	0.04	0.01	0.01
5	0.09	0.00	0.04	0.00	0.00	0.04
6 (wet)	N/A	N/A	N/A	N/A	N/A	N/A

Means Squared values at the Greenville Research Farm. The probability threshold is set at $\alpha = 0.10$, d.f. = 3. Only 5 of the 108 combinations had significant results.

Soil: Nebeker, fine, montmorillonitic, mesic Pachic Argixerolls

EC by Water Zone	**Bulk Density Shallow** 1-Ripped	2-Traffic	3-Plowpan	**Bulk Density Deep** 1-Ripped	2-Traffic	3-Plowpan
EC Shallow						
1 (dry)	9.05	151.16	37.55	36.59	171.73	39.49
2	18.28	1.78	3.82	3.26	29.85	4.41
3	8.97	793.39	71.09	0.40	664.94	63.22
4	204.12	333.25	344.51	232.77	531.06	69.39
5	2178.98	1491.85	1171.15	1287.45	1258.76	758.61
6 (wet)	877.61	347.23	163.10	867.95	341.51	218.19
EC Deep						
1 (dry)	45.77	80.54	224.87	47.67	93.93	252.41
2	12.59	104.19	218.99	5.28	76.25	109.93
3	0.74	1102.97	135.60	0.11	1027.47	184.29
4	26.44	367.75	537.85	94.00	539.68	247.45
5	2355.74	880.02	981.70	761.05	870.75	601.65
6 (wet)	447.08	236.65	667.27	490.57	242.05	785.49
NIR Reflectance						
1 (dry)	0.11	0.06	0.01	0.11	0.06	0.01
2	0.13	0.02	0.03	0.07	0.02	0.01
3	0.03	0.04	0.12	0.03	0.06	0.08
4	0.06	0.03	0.08	0.04	0.03	0.09
5	0.05	0.02	0.04	0.03	0.01	0.15
6 (wet)	0.04	0.03	0.04	0.07	0.03	0.05

Means Squared values at the Evans Research Farm. The probability threshold is set at $\alpha = 0.10$, d.f. = 3. 15 of the 108 combinations had significant results.

Soil: Kidman, coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls

	Bulk Density Shallow			Bulk Density Deep		
EC by Water Zone	1-Ripped	2-Traffic	3-Plowpan	1-Ripped	2-Traffic	3-Plowpan
EC Shallow						
1 (dry)	3.39	27.06	3.34	2.50	7.49	3.24
2	3.11	34.50	2.75	3.73	26.39	12.07
3	62.69	30.64	44.01	80.32	43.60	28.02
4	5.93	12.76	28.45	4.71	27.32	16.87
5	35.78	3.52	4.94	24.70	0.25	5.05
6 (wet)	39.63	1.32	5.89	37.70	1.47	4.43
EC Deep						
1 (dry)	8.84	15.46	16.96	10.71	21.61	20.11
2	1.94	3.69	17.73	1.78	23.37	19.24
3	14.17	2.03	22.02	15.52	3.55	13.38
4	3.53	2.08	4.40	5.07	2.14	3.55
5	18.37	3.21	2.08	14.57	5.44	2.35
6 (wet)	9.63	1.09	9.22	9.27	0.80	8.23
NIR Reflectance						
1 (dry)	0.01	0.02	0.03	0.04	0.01	0.03
2	0.01	0.00	0.01	0.01	0.00	0.02
3	0.01	0.02	0.01	0.03	0.02	0.01
4	0.09	0.00	0.05	0.06	0.02	0.01
5	0.01	0.02	0.00	0.01	0.01	0.00
6 (wet)	0.01	0.00	0.01	0.00	0.01	0.01

Means Squared values at the Kaysville Research Farm. The probability threshold is set at $\alpha = 0.10$, d.f. =3. 14 of the 108 combinations had significant results.